Fingerprint Mosaicing using Modified Phase Correlation Method

Thesis submitted in partial fulfillment of the requirements for the degree of

Master of Technology

in

Signal and Image Processing

by

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Rourkela, Odisha, India

June, 2015

Dedicated

to

my

Guide,

Elder brother

and

friends...

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the work in the thesis entitled **"Fingerprint Mosaicing using Modified Phase Correlation Method"** submitted by ***Satish H. Bhati*** is a record of an original research work carried out by him under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Electronics and Communication Engineering (Signal and Image Processing), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or academic award elsewhere.

Place: NIT Rourkela.
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DECLARATION

I hereby declare,

1. The work contained in the thesis is original and has been done by myself under the supervision of my supervisor.
2. The work has not been submitted to any other Institute for any degree or diploma.
3. I have followed the guidelines provided by the Institute in writing the thesis.
4. Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.
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Satish H. Bhati

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Satish H. Bhati

Abstract

Fingerprint is widely used biometric traits to identify individual due to uniqueness. However, the fingerprint identification is still a challenging task in forensic science for criminal investigation and identification due to less area of region of interest (i.e. ridges and valleys) in the obtained fingerprints. Entire fingerprint is obtained only when it is given intentionally. In the case of criminal incidents, it is not always possible to get entire fingerprints. In such cases, obtained fingerprints are often partial i.e. having less region of interest. Therefore, if it is possible to get more than one partial fingerprint of same finger, these can be combined to increase the area of interest using mosaicing process. This large fingerprint is used to compare with stored fingerprint database for identification.

The fingerprint mosaicing is the process of joining or stitching two or more than two partial fingerprint images and create a large view of fingerprint region containing ridges and valleys. The process contains mainly three steps: 1. Image registration, 2. Matching point extraction and 3. Image stitching.

The thesis proposes a fingerprint mosaicing algorithm using conventional phase correlation method with some modification. The method is a registration method which estimates only the translational and rotational parameters involved in the input images. The method also finds the single matching point in both images which is used to stitch both images. The method uses Fourier phase shift property to estimate the translational and rotational parameters involved in two partial fingerprints having overlapping region.

The conventional method has some drawbacks like the method can work successfully if and only if when the overlapping region is in the leftmost top corner in one of the two fingerprints. However, it does not always happen in

partial fingerprints obtained in forensic science. There are total six different possible positions of overlapping region in mosaiced fingerprint. The second drawback is that the method depends on the sequence of input, if the sequence is changed the output will also change and generate incorrect mosaiced fingerprint. As fingerprint images have only grey and white curvature lines (ridges and valleys), it not possible to predict the sequence of inputs by observing images. The last drawback is that the method generates mosaiced fingerprint though the input fingerprints do not have overlapping common region, thus method is unable to check the correctness of the generated output mosaiced fingerprint.

The thesis proposes a modified phase correlation method which can solve all these limitation of the previous conventional phase correlation method and make it more robust and efficient to be used practically.

Keywords: Cross power spectrum, Fingerprint mosaicing, Fourier transform, Minutiae point, Phase correlation method, Ridges and valleys, Rotational parameter, Translation parameter.

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Chapter 1

Introduction

1.1 Background

Among the all biometric traits (DNA, iris, retina, ear, face, gait etc.), fingerprint is the oldest and most widely used to identify individuals [1]. Fingerprints are unique among individuals and also among fingers of same individual. The uniqueness of a fingerprint is found by local ridge characteristics and their relationships. The fingerprint is the two dimensional representation of the epidermis, composed of pattern of ridge and valley (also called furrows) on the surface on the fingertips.

Fingerprint identification system has been widely adopted for user authentication due to its reliable performance and usability compared to other biometric systems. Recently, various types of fingerprint image acquisition sensors (including solid-state, thermal, optical, ultrasound, etc.) have been used in many forensic and commercial applications like criminal investigation, access control, e-commerce, issuing national ID cards and e-passports, etc.

The identification system compares the query fingerprint with stored fingerprint template database by matching different features in fingerprints. Minutiae points (ending and bifurcation points) are widely used as a feature in fingerprint identification system. The matching process can be easier and more accurate as the numbers of minutiae points (matching points) are increased in the query fingerprint. Therefore, it is advantageous to increase the number of minutiae points. It can be achieved by making fingerprint wider as much as possible. The fingerprints obtained in forensic science during criminal investigation are mostly partial [10]. These partial fingerprints have less area of interest i.e. less number of minutiae point. All the fingerprint recognition methods are mainly based on minutiae, which could be very few on small partial fingerprint images. Therefore, sometimes it is not possible for these methods to result in incorrect matches because of insufficient minutiae, or sometimes they are even not applicable for some partial fingerprints when there are no minutiae on them. The correct matching can be achieved by making fingerprint wider as much as possible. Experts can get more than one partial fingerprints during such criminal incidents like theft, robbery, murder, etc. It may be possible that experts obtain more than one partial fingerprints of same finger. These partial fingerprints can be combined using mosaiced process to widen the area of ridges and valleys in fingerprints, which results in more number of minutiae. Finally it improves the accuracy and robustness of identification system. Thus, fingerprint mosaicing is an important process in fingerprint identification system. It can be used as pre-processing before matching the test fingerprint with stored fingerprint templates. Fingerprint mosaicing helps to make fingerprint identification system more robust and accurate.

Fingerprint mosaicing is the similar to the image mosaicing. It stitches two or more than two partial fingerprints and combines them to create a large view of fingerprint. It is the seamless joining or stitching of two adjacent partial fingerprints. It is done by overlaying one fingerprint on other. Image registration process is used to find overlapped region in both images. Like all image mosaicing, fingerprint mosaicing also involves mainly three processes, i) Registration, ii) Stitching, and iii) Blending.

Image registration is the process to find the geometrical alignment between two images. The geometrical alignment can be achieved by finding the matching points or overlapping region between two fingerprint images. These matching points or overlapping region can be found by estimating the translational parameter between two fingerprints. The proposed algorithm uses the Fourier transform approach to estimate both parameters.

Image stitching is the process to seam or join two images and make them single image. First this process creates a large canvas, in which one fingerprint is superimposed on other fingerprint such that it overlaps on common region and looks like single continuous fingerprint.

Image blending is used to remove seam or visible edge at the joint of two fingerprints. In practice, due to atmospheric changes, variations in impression condition, acquisition methods, skin conditions etc., a significant change in the brightness and contrast between ridges and valleys of fingerprint can be noticed in the acquired partial fingerprints. Image blending is not a mandatory process in mosaicing. Simple average filtering at edge can be used as blending process to remove visible seam.

The phase correlation method is used as a registration method in this paper. It is a Fourier domain approach to find matching point in the two images translated and rotated with respect to one another. Fourier methods differ from other registration methods because they search for the optimal match using information in the frequency domain. The algorithm uses the Fourier shift property to estimate the translation parameter between two images by showing a distinct peak in the cross power spectrum at the point of the displacement. Rotational parameter is also estimated by repeating above process.

1.2 Fingerprint

Fingerprints are unique across individuals and across fingers of same individual. The uniqueness of a fingerprint is determined by local ridge characteristics and their relationships. It is a pattern of ridge and valley (also called furrows) on the surface on the fingertips. A total 150 different types of local ridge characteristics (like islands, enclosure, short ridges etc.) have been identified. The two most prominent ridge characteristics are called as minutiae. They are: 1. Ridge ending, 2. Ridge bifurcation as shown in Fig. 1.1. In general, a good quality fingerprint contains about 40-100 minutiae [2].

1.3 Thesis Motivation

Among all biometric traits, fingerprints have the highest level of reliability and have been extensively used by forensic experts in criminal investigations. The fingerprints obtained in forensic science and criminal investigations are mostly partial. These partial fingerprints have less area of interest i.e. less no. of features. Therefore, sometimes it is difficult to match with stored fingerprint templates. There is possibility that experts can obtain more than one partial fingerprints of same finger during such criminal incidents like theft, robbery, murder, etc. These partial fingerprints can be combined using mosaicing process to widen the area of interest of fingerprints, which results in more number of features. Finally it improves the accuracy, robustness of recognition system.

1.4 Thesis Objectives

The minutiae points (ridge ending and bifurcation), sweat pores along with texture features or structural information like orientation of ridges, pattern of ridges (arch, tented loop, right loop, left loop, twin loop, whorl etc.) are used

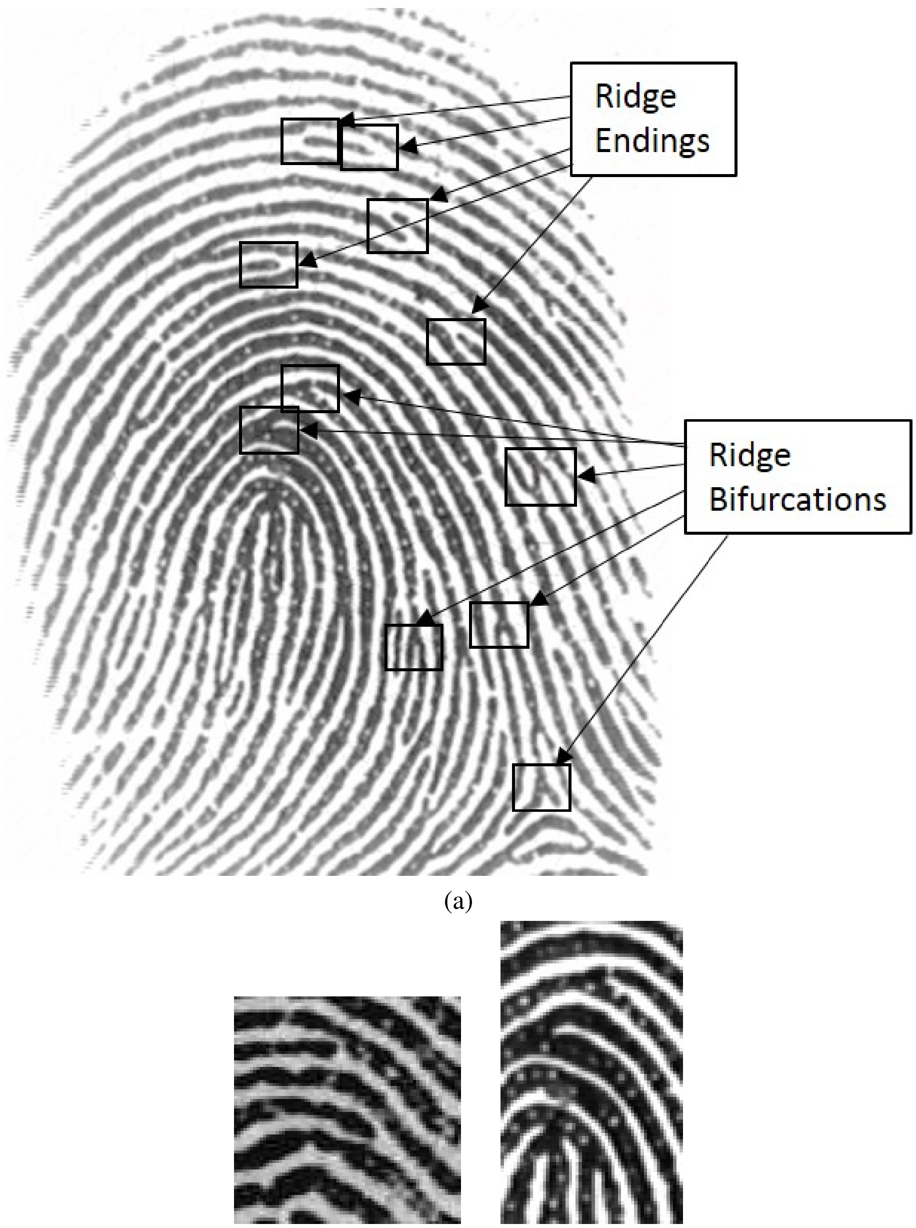


Figure 1.1: (a) Minutiae in a fingerprint image, (b) Ridge endings and (c) Ridge bifurcations

to match two fingerprints. These all important information which is required for matching, are increase as the area of fingerprint (ridges and valleys) is increased. The fingerprints obtained in forensic science are partial having less area of interest (ridges and valleys). Sometimes, the size of area is not enough such that the fingerprints are unable to provide sufficient information for matching. In such case, fingerprint mosaicing can be used to join the obtained partial fingerprints and make them large enough to get sufficient amount of information for matching purpose.

The objectives of the thesis are as follows.

1. Develop a fingerprint mosaicing algorithm using phase correlation method that can mosaicing two fingerprint images though the position of the overlapping region is not in the leftmost top corner of any fingerprint image.

2. Develop a sequence independent fingerprint mosaicing scheme that can always generate a correct mosaiced fingerprint image for any sequence of inputs.

3. Develop a correction check algorithm which can check the correctness of the generated output mosaiced fingerprint image and generates a message "Inputs do not have common overlapping region. So, it is not possible to mosaic them" if inputs do not have common overlapping region.

1.5 Thesis Organization

The thesis is organised in six chapters including the present chapter. The organisation of chapters is as follows:

Chapter 2: Literature Review

This chapter illustrates the chronological evolution of some competitive fingerprint mosaicing algorithms from various publications.

Chapter 3: The Phase Correlation Method

This chapter describes the pre-processing step fingerprint enhancement involved in the method. It explains the Fourier shifting property and how it is used to estimate translational and rotational parameter involved in the inputs. The drawbacks of method is mentioned in last.

Chapter 4: Proposed Overlapping Region Position Independent Algorithm

The chapter discuss the drawback of method of working only in the case when the overlapping region is in the leftmost top corner of one of two inputs. It also discusses the proposed algorithm to remove drawback and results.

Chapter 5: Proposed Input Sequence Independent Algorithm

The chapter describes the problem that the method depends on the sequence of inputs, the proposed algorithm and its results.

Chapter 6: Proposed Algorithm to check Presence of Overlapping Region

The chapter describe the drawback that the method is unable to check the presence of overlapping region in the inputs, the proposed algorithm and results.

Chapter 7: Conclusion and Future Scope

In this chapter, the overall thesis is concluded with the help of results and implementation. It also provide the analysis and future scope for research done.

Chapter 2

Literature Review

Chapter 2

Literature Review

Ratha et al. [13] grabbed the image sequence of a rolling fingerprint by a large a scanner and developed a mosaicing scheme to integrate multiple snapshots of a fingerprint. The authors examines five composition schemes that stack the grey scale images together and construct a composite mosaiced image, by associating a confidence value with every pixel. The efficacy of these schemes is evaluated by observing the quality of the composite image in terms of the number of valid minutiae points detected.

Jain et al. [14] considered fingerprint mosaicing as a 3D surface registration problem that can be solved using a modified Iterative Closest Point (ICP) algorithm. But this algorithm does not work for non-linear deformation of fingerprints. As the algorithm is time consuming due to iterative process, it cannot be used in real time application.

Zhang et al. [5] gave a hybrid algorithm which mosaics the stream of swipe fingerprint frames. Algorithm uses the minimum mean absolute error (MAE) as the registration criterion to find an integer translation that registers two adjacent swipe fingerprint frames to the nest integral pixel coordinates. While the extension phase correlation method with singular value decomposition is used to get sub-pixel precision. The mosaicing scheme assumes no rotation, scaling and shear effects involved in individual frames of the swipe fingerprint images.

The algorithm has a drawback that it does not work for some amount of elastic deformation.

Shah et al. [15] have proposed an algorithm called Thin Plate Splines (TPS) which is a 2D spatial generalization of the cubic spline. It is effective for estimating the deformation in fingerprints based on landmark points. The algorithm consists of three main steps- i) Coarse Alignment ii) Fine Alignment iii) Blending. The composite image is then enhanced in order to obtain the mosaiced template. This paper focuses on removal of elastic deformation but unable to identify the best pair of images suitable for mosaicing process.

Ross et al. [16] had given that mosaicing can be accomplished at two distinct levels: (a) The image level (image mosaicing), (b) the feature level (feature mosaicing).

Choi et al. [17] had designed a touchless system which consists of a camera and two planar mirrors. Three different views are captured in a single shot and mosaiced to form a single template.

Choi et al. [18] had given a Recursive Ridge Mapping algorithm which eliminates erroneous correspondences and decides how well the transformation is estimated by calculating the registration error with a normalized distance map. The method consists of three phases: feature extraction, transform estimation, and mosaicing.

Chapter 3

The Phase Correlation Method

Chapter 3

The Phase Correlation Method

3.1 Overview

The conventional phase correlation method is a single point registration method using Fourier domain approach. The method can register two images having transformation involving only translation and rotation. The method uses the Fourier shift property to estimate both translational and rotational parameters. The Fig. 3.1 shows the block diagram of the conventional phase correlation method.

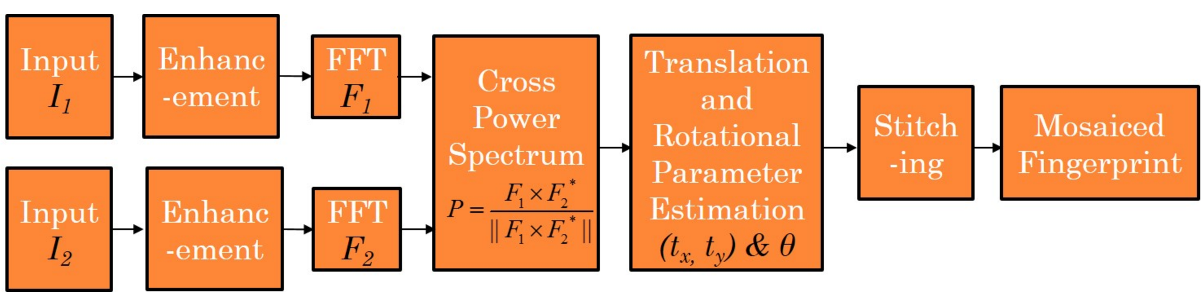


Figure 3.1: Block Diagram of Conventional Phase Correlation Method

3.2 Enhancement

Fingerprint enhancement is a pre-processing step in fingerprint mosaicing to improve the quality of fingerprints. In practice, due to variations in impression conditions, ridge configuration, and skin conditions etc., a significant percentage (approximately 10 percent) of acquired fingerprint images is of poor quality [2]. Enhancement improves the contrast between ridges and valleys in fingerprint image. There are many algorithm used to enhance the fingerprint image like Morphological operations, Gabor filtering, Fourier domain filtering, normalization using mean and variance, Histogram equalization, Adaptive Histogram equalization etc. Here, the adaptive histogram equalization method [9] is used to enhance fingerprint images. This process is not mandatory process. But still it is advantageous to enhance input fingerprints before processing because it helps in the fingerprint matching process.

(a) (b) (c)

(d) (e) (f)

Figure 3.2: (a) Original fingerprint, Enhanced fingerprint (b) using minimum and maximum pixel value of image, (c) using mean and variance of image, (d) using thresholding, (e) using histogram equalization, and (f) using adaptive histogram equalization.

3.3 Fourier Shift Property

The time shift property in Fourier transform for image is given by,
If $f(x,y) \leftrightarrow F(u,v)$, then

$$f(x-x_0, y-y_0) \leftrightarrow F(u,v) \times exp[-j2\pi(ux_0 - vy_0)/N] \tag{3.1}$$

Where N indicates size of image. x, y, u, and v vary from 0 to $(N-1)$.
The property says that multiplying $F(u,v)$ by the exponential term shifts the origin of the spatial function $f(x,y)$ from $(0,0)$ to (x_0, y_0).

3.4 Estimation of Translational Parameter

Using above property, if I_1 and I_2 are two images that differ only by a displacement (x_0, y_0) then these can be related by,

$$I_2(x,y) = I_1(x-x_0, y-y_0) \tag{3.2}$$

In the frequency domain, their corresponding Fourier transform F_1 and F_2 are related by,

$$F_2(u,v) = F_1(u,v) \times exp[-j2\pi(ux_0 - vy_0)/N] \tag{3.3}$$

The cross phase spectrum of two images is defined as the normalized value of the multiplication of Fourier transform of first image and conjugate of the Fourier transform of the second image.
According to that the cross power spectrum of I_1 and I_2 using Fourier transform F_1 and F_2 is given by,

$$\frac{F_1(u,v) \times F_2^*(u,v)}{\|F_1(u,v) \times F_2^*(u,v)\|} \tag{3.4}$$

where, F_2^* is complex conjugate of F^2 and $\|\|$ indicates absolute value of complex matric.

As the 2D DFT is complex, F_1 and F_2 can be expressed in polar form,

$$F_1(u,v) = \|F_1(u,v)\| \times e^{j\phi_1(u,v)} \tag{3.5}$$

$$F_2(u,v) = \|F_2(u,v)\| \times e^{j\phi_2(u,v)} \tag{3.6}$$

Using Eq. 3.5 and 3.6 in 5.2,

$$\frac{F_1(u,v) \times F_2^*(u,v)}{\|F_1(u,v) \times F_2^*(u,v)\|} = \frac{\|F_1(u,v)\| \times e^{j\phi_1(u,v)} \times \|F_2^*(u,v)\| \times e^{-j\phi_2(u,v)}}{\|\|F_1(u,v)\| \times e^{j\phi_1(u,v)} \times \|F_2^*(u,v)\| \times e^{-j\phi_2(u,v)}\|} \tag{3.7}$$

As $\|F_1 \times F_2\| = \|F_1\| \times \|F_2\|$ and $\|e^{j\phi}\| = 1$, we get

$$\frac{F_1(u,v) \times F_2^*(u,v)}{\|F_1(u,v) \times F_2^*(u,v)\|} = e^{j\phi_1(u,v) - j\phi_2(u,v)} \tag{3.8}$$

The left side term in above equation give the phase difference between two images which can be represented by single exponential term.
Here, images have displacement of (x_0, y_0). Therefore, the phase difference between images is also given in terms of (x_0, y_0) as

$$e^{j\phi_1(u,v) - j\phi_2(u,v)} = e^{j2\pi(ux_0 - vy_0)/N} \tag{3.9}$$

Finally the cross power spectrum is given by,

$$\frac{F_1(u,v) \times F_2^*(u,v)}{\|F_1(u,v) \times F_2^*(u,v)\|} = e^{j2\pi(ux_0 - vy_0)/N} \tag{3.10}$$

Thus, the cross power spectrum of any two images having displacement always gives exponential term.
If we take inverse Fourier transform of the above cross power spectrum i.e. exponential term, we get a spectrum having shifted Impulse function as derived below.

$$\xi^{-1}[e^{j2\pi(ux_0 - vy_0)/N}] = \delta(x - x_0, y - y_0) \tag{3.11}$$

This shifted Impulse can be seen as the distinct peak in the spectrum. The spectrum has zero value everywhere except at the (x_0, y_0), which is the location of peak in the spectrum. If there is no transformation other than translation between I_1 and I_2, the spectrum gives a distinct peak at the point of the displacement.

3.5 Estimation of Rotational Parameter

Suppose the images I_1 and I_2 involve both translation and rotation. Let the angle of rotation is "θ" between them. Now, if I_1 is rotated by an angle of θ, there will be only translation left between the images and the cross power spectrum should give a maximum peak. So, I_1 is rotated by 1° each time and the distinct peak is computed for that angle. Thus, I_1 is rotated for 0° to 359° and the magnitude of distinct peak is stored in a vector. The index of the vector that has highest peak becomes the angle of rotation "θ". Thus, the involved rotational parameter is estimated.

3.6 Results and Discussion

3.6.1 Mosaicing of two fingerprint involving only translation parameter

We have taken two partial fingerprint of poor quality as shown in Fig. 3.3(a) and 3.3(b). Both are enhanced using adaptive histogram equalization method. The enhanced fingerprints are shown in Fig. 3.3(c) and 3.3(d). Now these enhanced fingerprints are applied to phase correlation method to estimate translation parameter. The cross power spectrum is shown in 3.3(f) which shows the displacement of $(48, 98)$ between fingerprints. The estimated overlapping region in inputs are is shown in 3.3(g) and 3.3(h). The final mosaiced fingerprint is obtained by superimposed second input on the first input at the overlapping region. The mosaiced fingerprint is shown in 3.3(i).

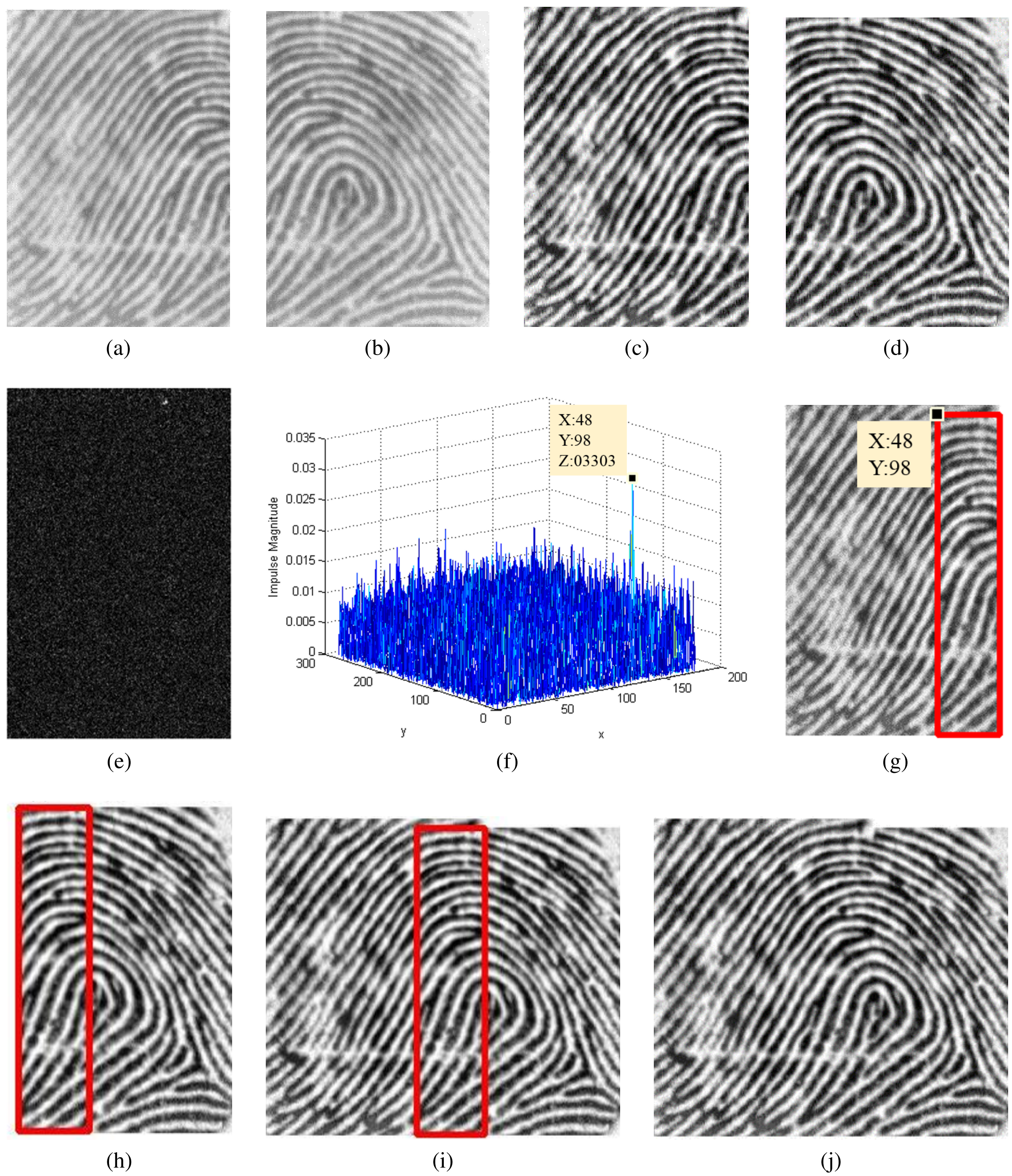


Figure 3.3: (a) and (b) Input fingerprints, (c) and (d)Enhanced fingerprints (e) Cross power spectrum in 2D plane, (f) cross power spectrum in 3D space with distinct peak, (g) and (h) Estimated overlapping region in input Fingerprints respectively, (i) Mosaiced fingerprint with overlapping region and (j) Mosaiced fingerprint image.

3.6.2 Mosaicing of two fingerprint involving both translation and rotational parameters

We have taken two input fingerprints involving both the translational and rotational parameter as shown in Fig. 3.4(a) and 3.4(b). Here, we rotate first fingerprint by 1° in clockwise direction every time and apply similar steps as applied to find translational parameter. The magnitude of peak in spectrum is stored in a vector for each rotation. The fig. 3.4(c) shows that the highest magnitude is obtained for the angle 316°. Thus, the estimated rotational parameter is 315°. The Fig.3.4(d) is first fingerprint after rotation of 315° in clockwise direction. Now, this fingerprint and second fingerprints are used to find translational parameter involved and stitched. The Fig. 3.4(e) is mosaiced fingerprint.

3.7 Drawbacks of Method

The conventional phase correlation method has three disadvantages. They are given below:

i) The method only works successfully in the case when the overlapping region is at the leftmost top corner of right side fingerprint.

ii) The change in the sequence of input fingerprints affects the output mosaicked fingerprint.

iii) The algorithm gives mosaiced fingerprint though the input fingerprints do not have overlapping region. The algorithm is unable check correctness of output mosaiced fingerprint.

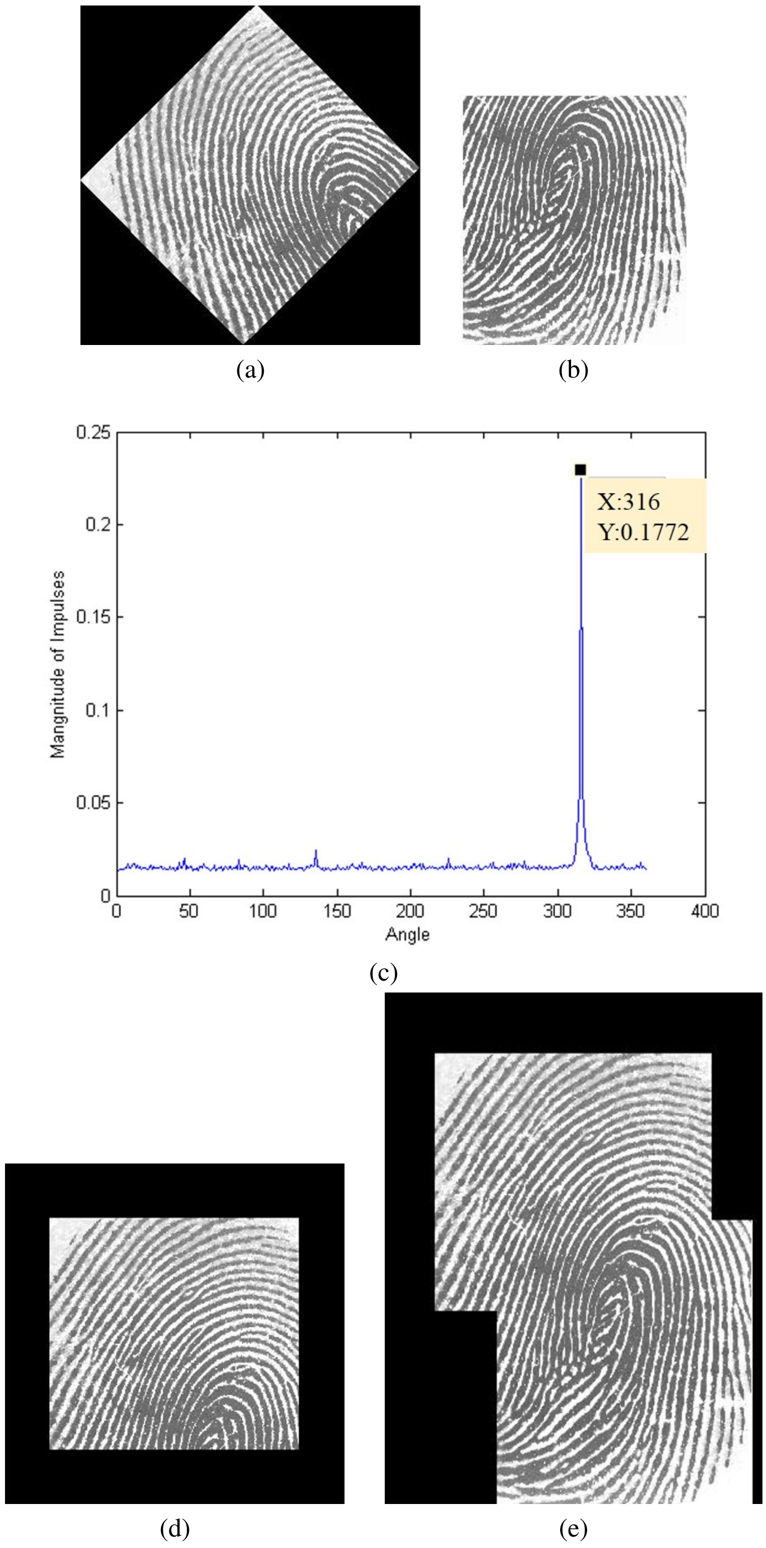


Figure 3.4: (a) and (b) Input fingerprint, (c) Estimation of rotational parameter, (d) First fingerprint with rotation of estimated rotational parameter and (e) Mosaiced fingerprint.

3.8 Summary

The phase correlation method is FFT based method which find the location of distinct peak in the spectrum which is translation parameter. Thus, it is a single point registration method. It can estimate translational as well as rotational parameter involved in two images.

Chapter 4

Proposed Overlapping Region Position Independent Algorithm

Chapter 4

Proposed Overlapping Region Position Independent Algorithm

4.1 Overview

The conventional phase correlation method generates correct mosaiced image if and only if any one of two input images has the common overlapping region at the leftmost top corner of second input image. However it is not always happened in the case of partial fingerprint images of forensic science. It is observed from the experiments that there are six possible positions of overlapping region in the input images.

4.2 Six Possible Positions of Overlapping Region

The previous algorithm in [3], [4], [5] and [6] shows correct mosaiced fingerprint if and only if the second input fingerprint contains the overlapping region in the leftmost top corner of fingerprint. It is not always possible in the forensic that the obtained partial fingerprints satisfy above condition. There can be six possible ways in which two fingerprints can be overlapped as shown in FIg. 4.1. We consider each way as a case.

The algorithm works only for case 1, 3 and 5 which are shown in Fig. 1(a),

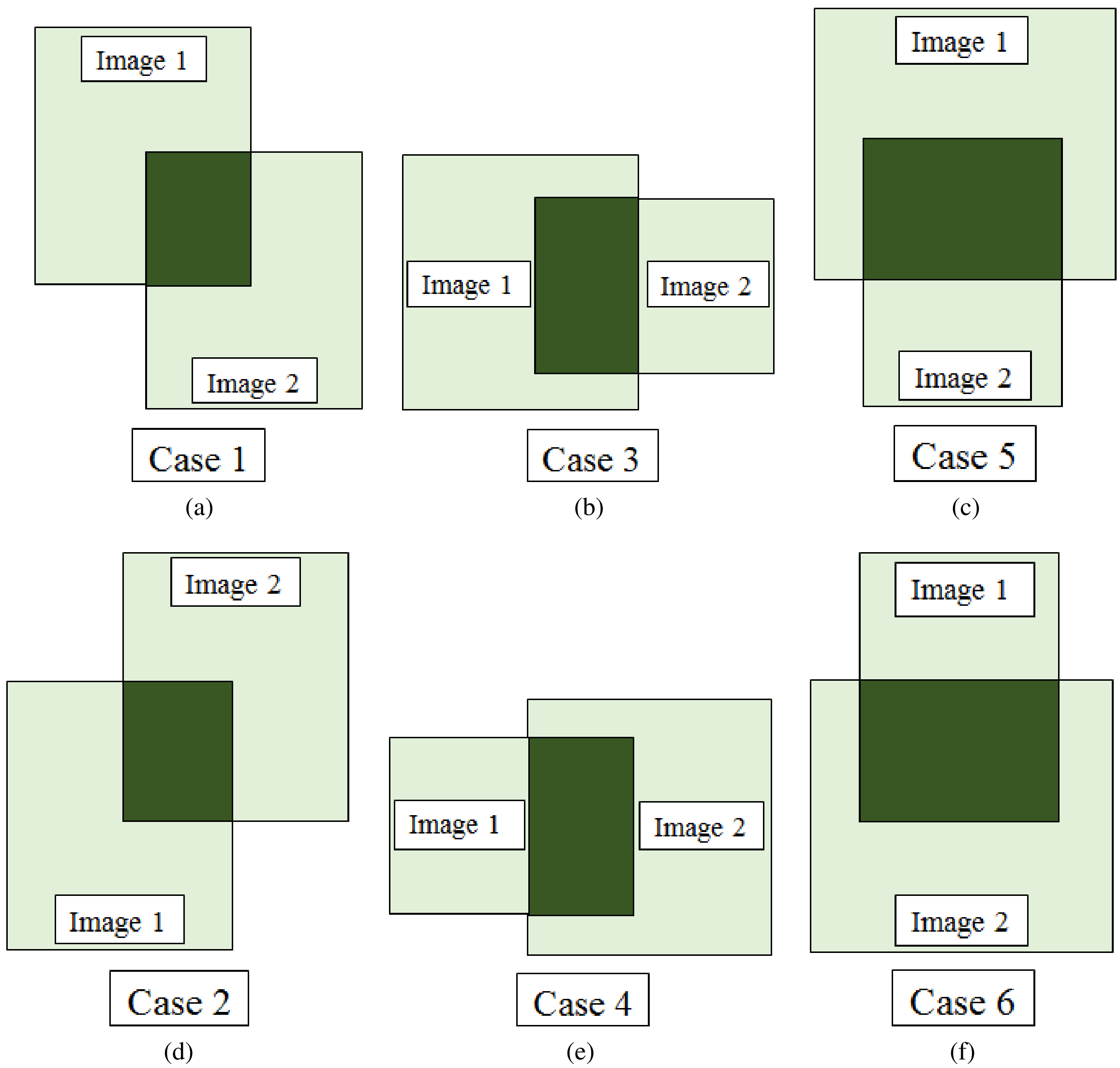


Figure 4.1: Different types of possible ways in which two fingerprints can be overlapped.

1(b) and 1(c). In these three cases, the leftmost top corner of second image contains the overlapping region. The algorithm gives incorrect mosaiced fingerprint for remaining three cases 2, 4 and 6 which are shown in Fig. 4.1(d), 4.1(e) and 4.1(f).

The previous algorithm works only for case 1, 3 and 5. In these three cases, the leftmost top corner of image2 contains the overlapping region. The previous algorithm shows correct result only for these three cases 1, 3 and 5. It gives incorrect mosaiced fingerprint for remaining case 2, 4 and 6. The proposed algorithm solves this problem and shows correct results for all cases using mirror image phenomenon.

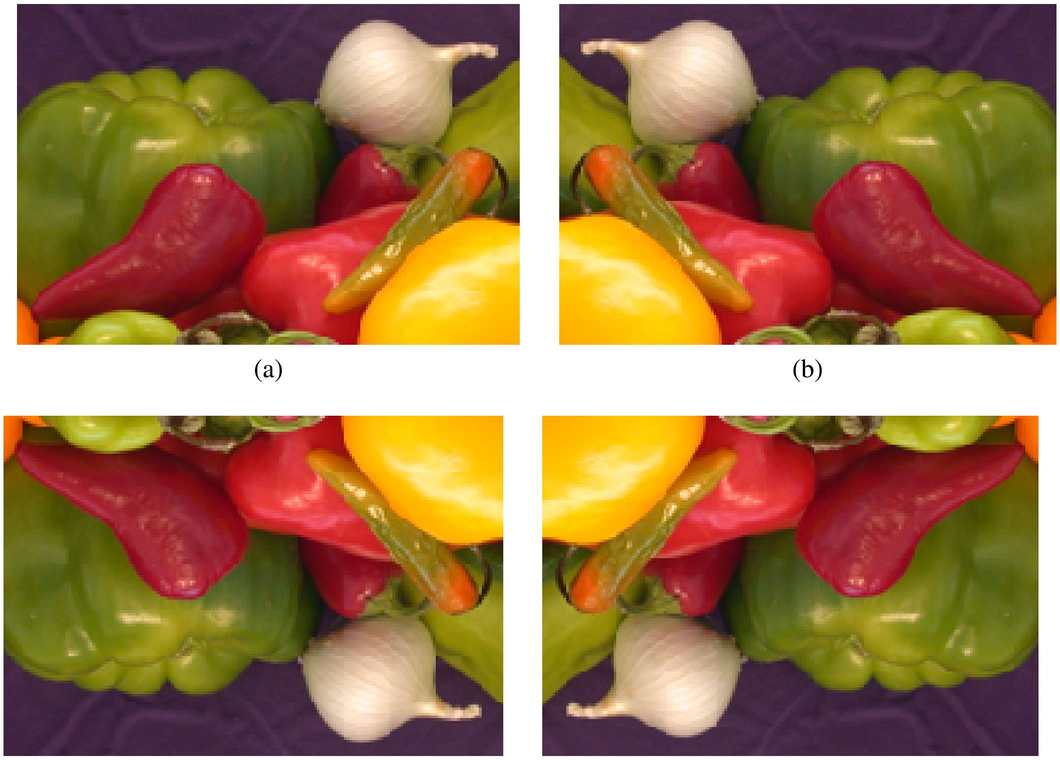
4.3 Proposed Solution

The proposed algorithm converts the input fingerprints in such a way that these satisfy the condition of having overlapping region at the leftmost top corner of one input fingerprint. After that, the translation parameter involved in input fingerprints is estimated using conventional phase correlation method. Finally, two input fingerprints are stitched at estimated translation parameter. The mosaiced fingerprint is again converted to similar mirrored image as applied before the phase correlation method to input fingerprints to find mosaiced fingerprint of original input fingerprints. The correctness of the mosaiced fingerprint can be checked by observing ridges and valleys. In correct mosaiced fingerprint, ridges and valleys alternate and flow in a locally constant direction [1].

4.4 Mirror Image Transformation

There can be three possible different mirrored-images of an image. These are i) Side mirrored image, ii) Down side mirrored image, iii) Down side mirrored image of side mirrored image which are as shown in Fig. 4.2. It can be observed that the Fig. 4.2(b) is the side mirrored image of Fig. 2(a) and Fig. 4.2(c) is down side mirrored image of Fig. 4.2(a). Also Fig. 4.2(d) is down side mirrored image of side mirrored image of Fig. 4.2(a).

The side mirrored image can be found just by reversing the sequence of column of pixels in the image. If C is the number of columns in image, then Xth column is interchanged with $(C-X+1)^{th}$ column in image. Similarly, the down side mirrored image can be found by reversing the sequence of rows



(a) (b)

(c) (d)

Figure 4.2: (a) Original image, (b) Side mirrored image of original image, (c) Down side mirrored image of original image, (d) Down side mirrored image of side mirrored image of original image.

of pixels in the image. If R is the number of rows in image, then Y^{th} row is interchanged with $(R-Y+1)^{th}$ row. The necessity of finding mirrored image of fingerprint is to convert the inputs such a way that the translation parameter is calculated correctly using phase correlation method.

As shown in Fig. 4.3(a), it can be observed that case 2 and 4 are the sided mirror image of case 1 and 3 respectively. Similarly, case 6 and 2 is the down side mirror image of case 5 and 1respectively as shown in Fig. 4.3(b). Thus, we can divide all cases into three categories. ***Category 1***, includes case 1, 3 and 5. They do not need to be converted to other cases by mirror image. ***Category 2***, includes case 2 and 4, which need to be converted into case 1 and 3 respectively using sided mirror image. ***Category 3***, includes case 6 and 2. They need to

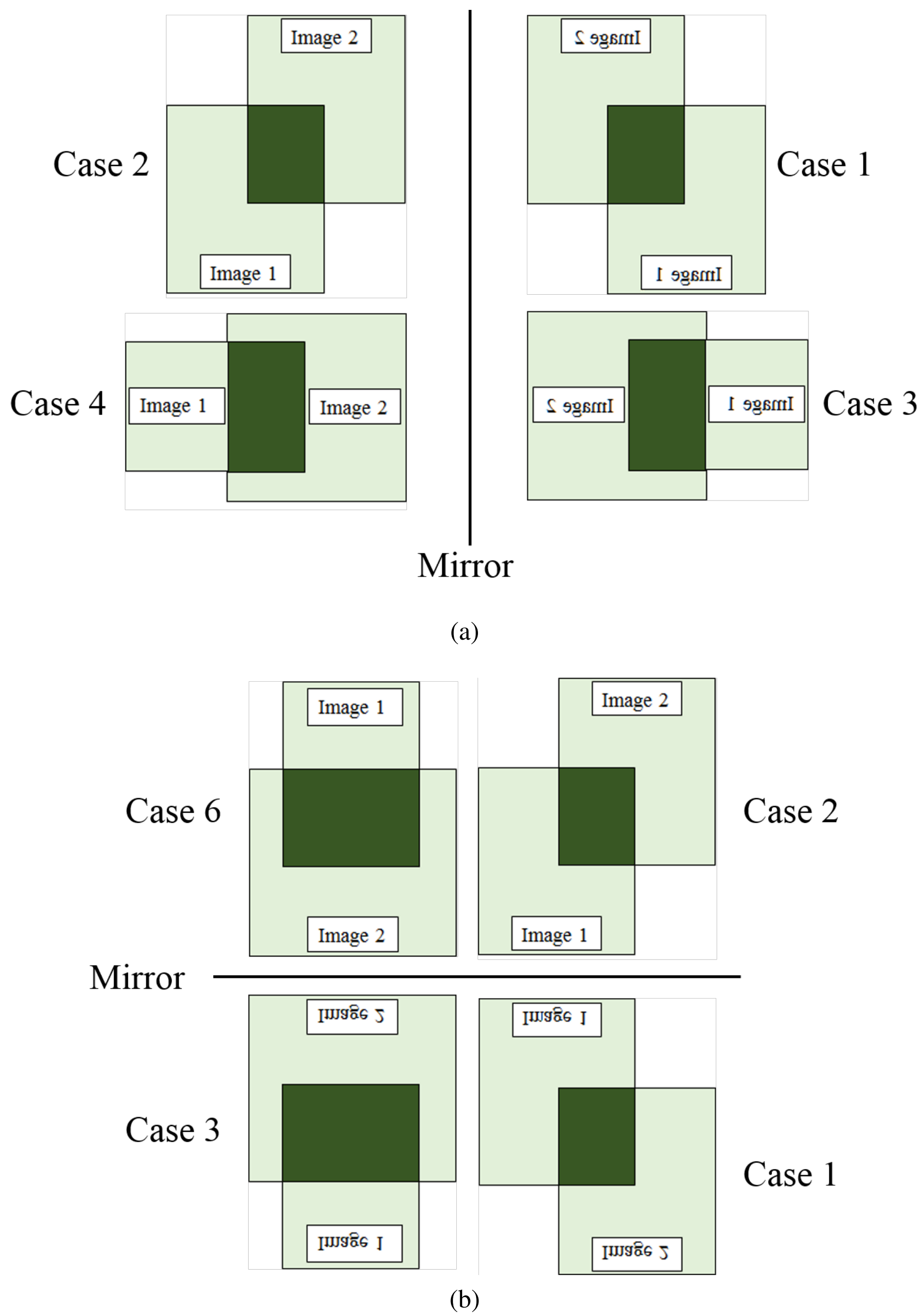


Figure 4.3: (a) Side mirrored image of case 2 and 4, (b) Down side mirrored image of case 6 and 2.

be converted into case 3 and 1 respectively using down sided mirror image. Our method finds mirror images of both input fingerprints to convert them into category 1 and then proceeds the same steps as for category 1. At the end of process, the result shows mosaiced fingerprint of mirrored input fingerprints. Now the mirror of mirror image is the same image. So again we find the same mirror image of obtained mosaiced fingerprint as we use at starting. Resultant mirror image shows the mosaiced fingerprints of actual input fingerprints.

4.5 Results and Discussion

In our proposed algorithm, the conventional phase correlation method is applied to side mirror image of both inputs as shown in Fig. 4.4(c) and 4.4(d) instead of direct inputs. It estimates the translation parameter correctly and also mosaics fingerprints correctly as shown in Fig. 4.4(i) and Fig. 4.4(k). The mosaiced fingerprint is correct due to alternative ridges and valleys in continuous direction. Fig. 4.4(l) shows the actual mosaiced fingerprint of original input fingerprints, which is side mirror image of the mosaiced fingerprint of Fig. 4.4(h). Similarly, we can find correct mosaiced fingerprint for Case 4 using the side mirror image transformation. The results is shown in 4.5 for Case 4. In Case 6, we find downside mirror image instead of side mirror image of inputs and after that mosaic correctly. The results is shown in 4.6 for Case 6.

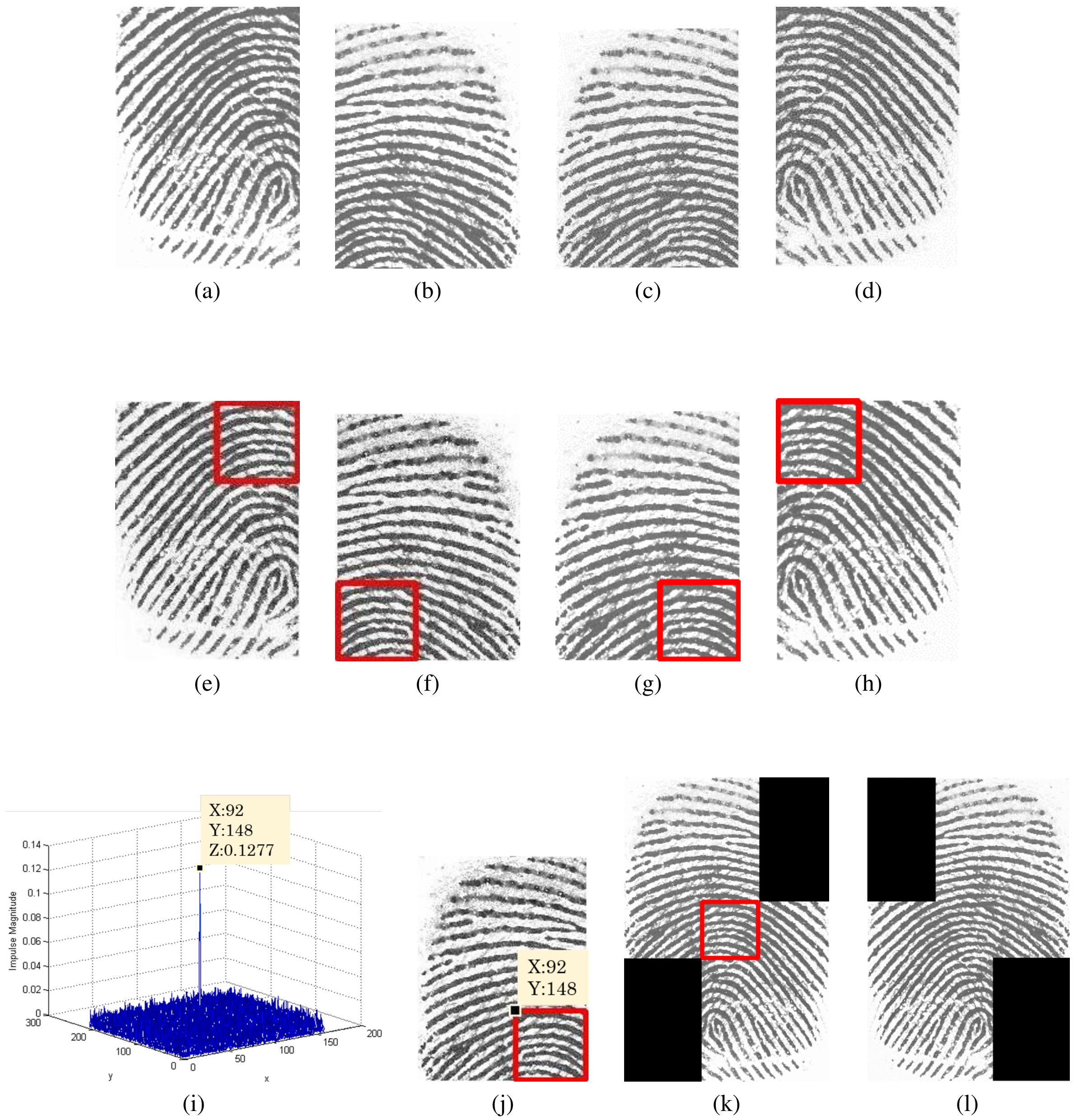


Figure 4.4: (a) and (b) Input fingerprints, (c) and (d) Overlapping region in inputs respectively, (e) and (f) Side mirrored image of inputs respectively, (g) and (h) Side mirrored image of (c) and (d) respectively, (i) Cross power spectrum of mirrored images, (j) Estimated overlapping region in first mirrored image, (k) Mosaiced fingerprint, (l) Side mirrored image of mosaiced fingerprint.

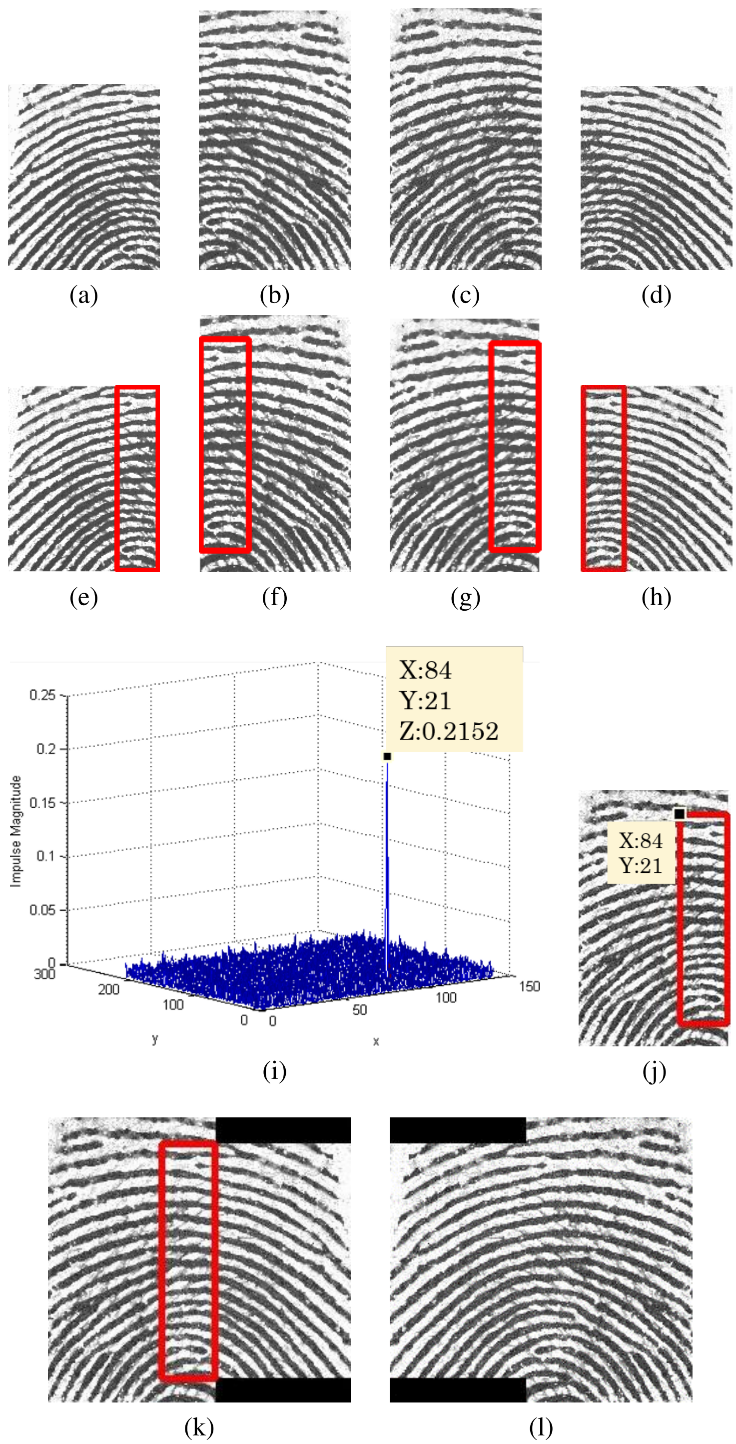


Figure 4.5: (a) and (b) Input fingerprints, (c) and (d) Overlapping region in inputs respectively, (e) and (f) Side mirrored image of inputs respectively, (g) and (h) Side mirrored image of (c) and (d) respectively, (i) Cross power spectrum of mirrored images, (j) Estimated overlapping region in first mirrored image, (k) Mosaiced fingerprint, (l) Side mirrored image of mosaiced fingerprint.

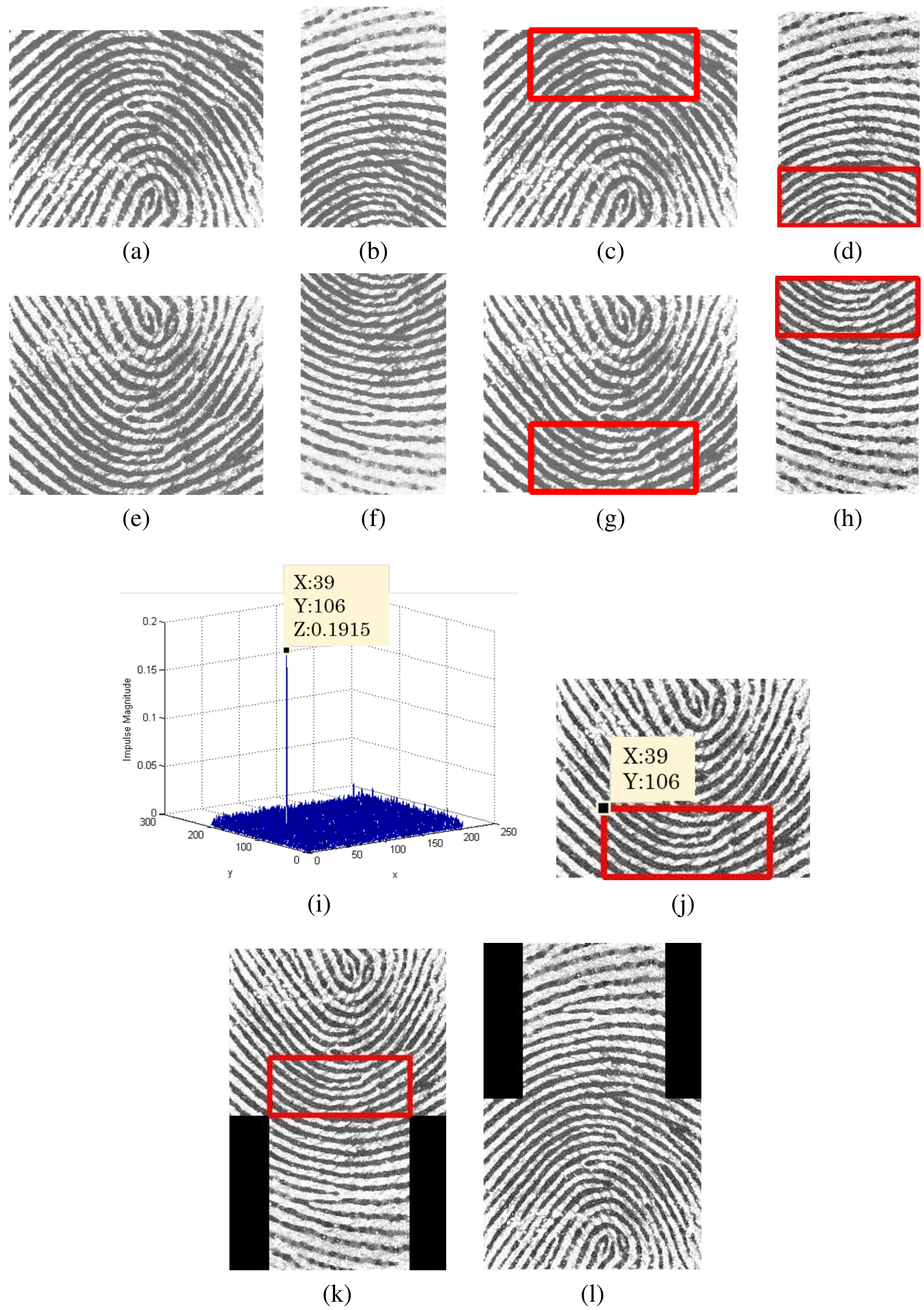


Figure 4.6: (a) and (b) Input fingerprints, (c) and (d) Overlapping region in inputs respectively, (e) and (f) Down side mirrored image of inputs respectively, (g) and (h) Down side mirrored image of (c) and (d) respectively, (i) Cross power spectrum of mirrored images, (j) Estimated overlapping region in first mirrored image, (k) Mosaiced fingerprint, (l) Down side mirrored image of mosaiced fingerprint.

4.6 Summary

The proposed algorithm converts the input fingerprints in such a way that these satisfy the condition of having overlapping region at the leftmost top corner of one input fingerprint. Thus, proposed algorithm first converts input fingerprints of case 2, 4 (***Category 2***) and case 6 (***Category 3***) into case 1, 3 and 5 (***Category 1***) respectively using mirrored image i.e. the ***Category 2*** and ***Category 3*** are converted to ***Category 1***. After that, similar steps are applied to mosaic fingerprints. The output mosaiced fingerprint is the mosaic of mirrored image of inputs. Therefore, we find the mirrored image of mosaiced fingerprints which is the actual mosaiced output of original input fingerprints.

Chapter 5

Proposed Input Sequence Independent Algorithm

Chapter 5

Proposed Input Sequence Independent Algorithm

5.1 Overview

In the case of different types of images like landscape photos (images of natural scene containing mountains, trees, pyramids etc.), wildlife photos (images of animals), aerial photos (pictures captured from a higher altitude such as planes, parachutes, air balloons and skyscrapers), architectural photos (shots of structures, houses and buildings from different angles) and real life photography, it is easy to decide between two input images whether images need to join side by side or up down manner. But it is too difficult in case of fingerprints because these only contain black and white curvature lines (ridges and valleys). If these need to be joined side by side, then it is not possible to decide which fingerprint will be in left side and which one will be in right side in the mosaiced fingerprint. Similarly if these need to be joined in up down manner, then it is difficult to predict which fingerprint will be upper and which one will be lower in the mosaiced fingerprint.

The conventional phase correlation method mosaics two images having overlapping region by estimating translation parameter using the location of the distinct peak in the cross phase spectrum of Fourier transforms of both input images. The experiment shows that if we change the sequence of inputs, however cross phase spectrum will show distinct peak. Therefore, if the images are stitched by estimating the translation parameter obtained from cross phase spectrum of inputs after changing the sequence of inputs, the images are mosaiced incorrectly. Thus, the conventional phase correlation method is input sequence dependent. The change of sequence of inputs leads to generate incorrect mosaiced image.

The conventional phase correlation method has a limitation that the change of sequence of inputs changes the output. The method gives correct mosaiced image if input images have overlapping region and if and only if the first input and second input images are the left side image and right side image respectively in the mosaiced image. If the sequence of these input images is exchanged then the method generates incorrect mosaiced image. The proposed algorithm solves that limitation.

5.2 The Ways of Stitching Two Images

It is observed from experiment that if the sequence of the input images is changed in the phase correlation method then the corresponding cross phase spectrum remain same except the position of the distinct peak is changed. There are three possible ways in which two images might be needed to stitch to mosaic them. These three ways are shown in Fig. 5.1.

As distinct peak in spectrum shows the position of matching point in the first input image where second image is needed to stitch to mosaic both images. In the case of horizontally stitched image, the location of the peak is always in the first row of pixels in the spectrum as shown in the Fig. 5.1(a). Similarly, the peak is located in the first column of the pixels of spectrum in the case of vertically stitched image as shown if Fig. 5.1(b). In the case of diagonally

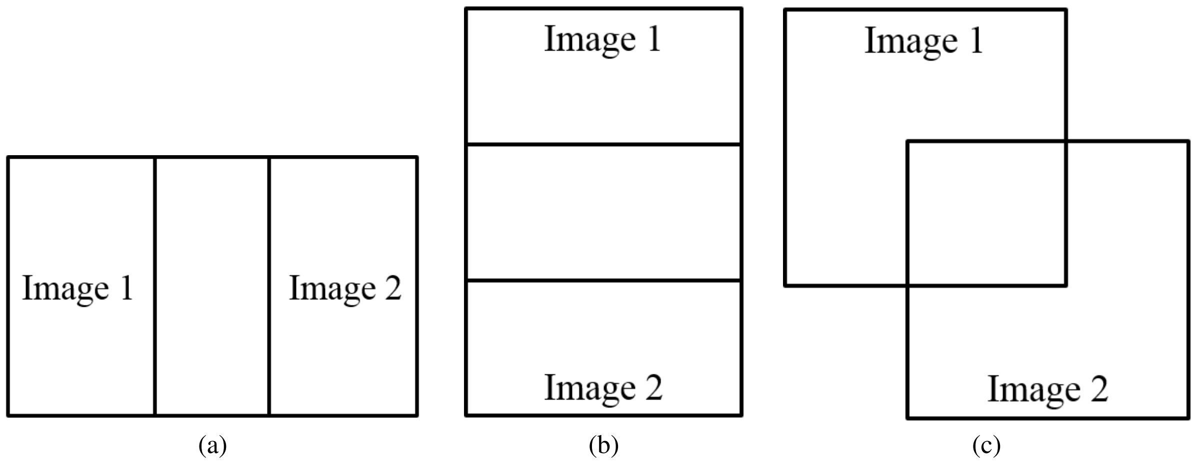


Figure 5.1: (a) Horizontally stitched image, (b) Vertically stitched image, (c) Diagonally stitched image.

stitched image, it can be observed from Fig. 5.1(c) that the location of the matching point (peak in spectrum) is at anywhere in the plane of Image 1 except the first row and first column of the pixels of Image 1.

5.3 The Effect of change of Sequence of Inputs on Cross Power Spectrum

5.3.1 Theoretical Analysis

The cross power spectrum of two images, I_1 and I_2 is defined using Eq. (3.10) as

$$\frac{F_1(u,v) \times F_2^*(u,v)}{\|F_1(u,v) \times F_2^*(u,v)\|} = e^{j2\pi(ux_0 - vy_0)/N} \tag{5.1}$$

Now if the sequence of the inputs are changed i.e. I_2 is inputted first and I_1 is second, then the spectrum is defined as

$$\frac{F_2(u,v) \times F_1^*(u,v)}{\|F_2(u,v) \times F_1^*(u,v)\|} \tag{5.2}$$

From Eq. (3.8), we get

$$\frac{F_2(u,v)\times F_1^*(u,v)}{\|F_2(u,v)\times F_1^*(u,v)\|}=e^{j\phi_2(u,v)-j\phi_1(u,v)} \tag{5.3}$$

If $e^{j\phi_1(u,v)-j\phi_2(u,v)}=e^{j2\pi(ux_0-vy_0)/N}$, then

$$e^{j\phi_2(u,v)-j\phi_1(u,v)}=e^{j2\pi(\mp ux_0\mp vy_0)/N} \tag{5.4}$$

Thus, the cross power spectrum after the change of sequence of inputs is given by

$$\frac{F_2(u,v)\times F_1^*(u,v)}{\|F_2(u,v)\times F_1^*(u,v)\|}=e^{j2\pi(\mp ux_0\mp vy_0)/N} \tag{5.5}$$

By taking inverse Fourier transform of above expression, we get

$$\xi^{-1}[e^{j2\pi(\mp ux_0\mp vy_0)/N}]=\delta(x\pm x_0,y\pm y_0) \tag{5.6}$$

The left side term is the shifted impulse function. Therefore, if the sequence of the inputs is changed then the distinct peak changes the position from (x_0,y_0) to $(\mp x_0,\mp y_0)$ i.e. $(-x_0,y_0)$ or $(x_0,-y_0)$ or $(-x_0,-y_0)$.
Thus, there are three possible position of peak in the spectrum if the sequence of inputs is changed.

5.3.2 Time Reversal Property

The time reverse property in time domain is given as below.
Let a 1D 6 sample discrete time sequence $f(t)$.
$f(t)=3,0,1,2,-1,2$

Using the time reversal property, this impulse function can be also represented as below:

$$\delta(x+x_0,y-y_0)=\delta(x\text{–}(-x_0),y-y_0)=\delta(x\text{–}(W+1-x_0),y-y_0) \tag{5.7}$$

$$\delta(x-x_0,y+y_0)=\delta(x-x_0,y-(-y_0))=\delta(x-x_0,y-(H+1-y_0)) \quad (5.8)$$

$$\delta(x+x_0,y+y_0)=\delta(x-(-x_0),y-(-y_0))=\delta(x-(W+1-x_0),y-(H+1-y_0)) \quad (5.9)$$

Where $H \times W$ is the size of the cross power spectrum.

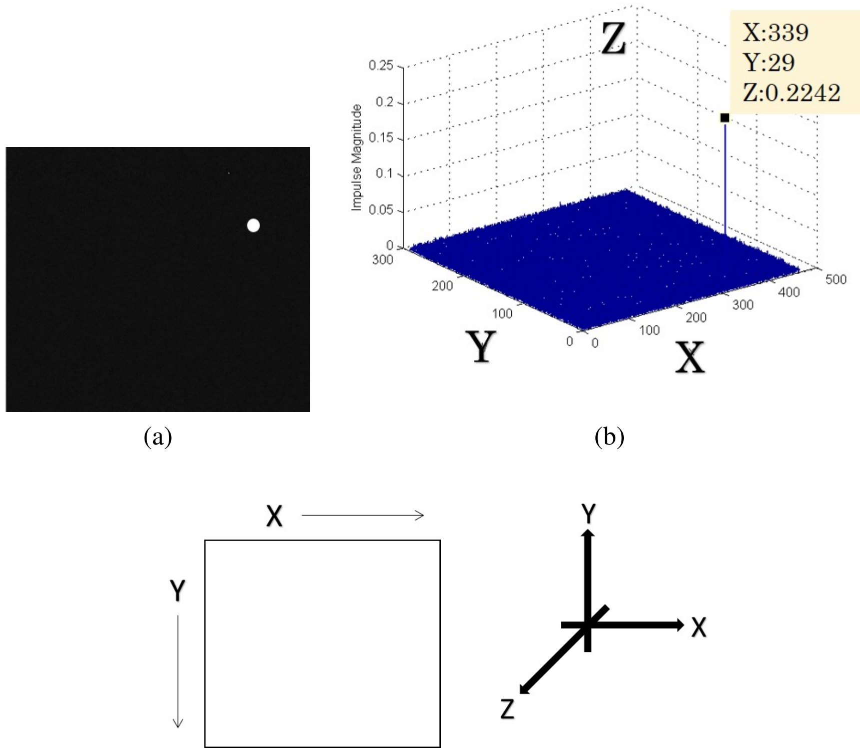
Thus, the change of the sequence of inputs changes only the position of pixels in the spectrum. The position of distinct peak is also changed in spectrum. As a result the position of the matching point in the image at which images are needed to be stitched is also changed. Thus, if (x_0,y_0) is the position of peak in the spectrum for the given sequence of input images and the sequence of the inputs is changed, then the position of peak is changed form (x_0,y_0) to $(x–(W+1-x_0),y-y_0)$ or $(x-x_0,y-(H+1-y_0))$ or $(x-(W+1-x_0),y-(H+1-y_0))$. Thus, there are three possible case of change of position of distinct peak in spectrum

5.3.3 Practical Analysis

We can represent the effect of change of sequence of inputs on the cross power spectrum graphically as below:

If we consider an image is in 3D X-Y-Z space where image lays in X-Y plane as shown in Fig. 5.2. X axis is in the direction of column of pixels and Y axis is in the direction of rows of pixels and Z axis is perpendicular to the image.

There are three possible cases in which image can be stitched to mosaic as discussed in section 5.2. We have performed experiments on all three types of mosaiced images and observed change in the spectrum. It is observed that when the sequence of the inputs is changed, the spectrum have same magnitude but only the position of pixels are changed. It is also observed the the position of pixels is changed by rotating the spectrum with respect to one of three axis



(a) (b)

(c) (d)

Figure 5.2: (a) Cross power spectrum as image in 2D plane, (b) Cross power spectrum in 3D space, (c) 2D spectrum in X-Y plane, (d) 3D spectrum in X-Y-Z space.

of X-Y-Z space. The axis of rotation depends on the type of mosaiced image as mentioned in section 5.2. We have considered three cases for three types of mosaiced images to discuss how the spectrum is changed after the changing the sequence of inputs.

Case 1: Horizontally mosaiced image In this case, the peak is always located in first row in the 2D spectrum i.e. along Y-axis in the 3D spectrum. It is observed from experiments that the 3D spectrum is rotated by 180° with respect to Y-axis when the sequence of inputs is changed as shown in Fig. 5.3(c). It can be observed from Fig. 5.3(d) that the location of peak is still in the first row of 2D spectrum after rotating spectrum. Thus, the Y coordinate of the position of peak is not changed though the sequence of inputs is changed in the case of horizontally mosaiced image. Only X coordinate is changed

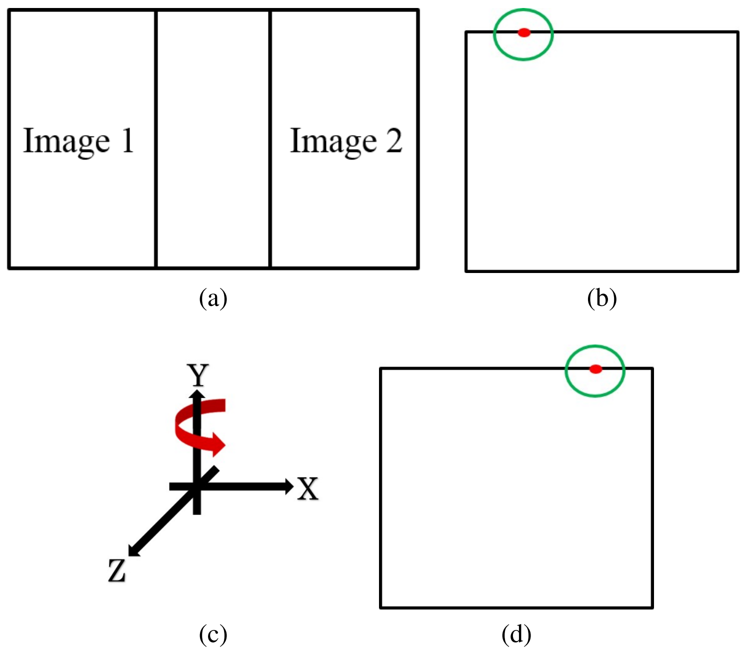


Figure 5.3: (a) Horizontally mosaiced image, (b) Cross power spectrum for horizontally mosaiced image, (c) Rotation of 180° with respect to Y axis, (d) 2D spectrum after rotation.

according to time reversal property.

Case 2: Vertically mosaiced image In this case, the peak is always located in first column in the 2D spectrum i.e. along X-axis in the 3D spectrum. It is observed from experiments that the 3D spectrum is rotated by 180° with respect to X-axis when the sequence of inputs is changed as shown in Fig. 5.4(c). It can be observed from Fig. 5.4(d) that the location of peak is still in the first row of 2D spectrum after rotating spectrum. Thus, the X coordinate of the position of peak is not changed though the sequence of inputs is changed in the case of horizontally mosaiced image. Only Y coordinate is changed according to time reversal property.

Case 3: Diagonally mosaiced image In this case, the peak is always located in X-Y plane except first row and first column in the 2D spectrum. It is observed from experiments that the 3D spectrum is rotated by 180° with respect to Z-axis when the sequence of inputs is changed as shown in Fig. 5.5(c). It can be

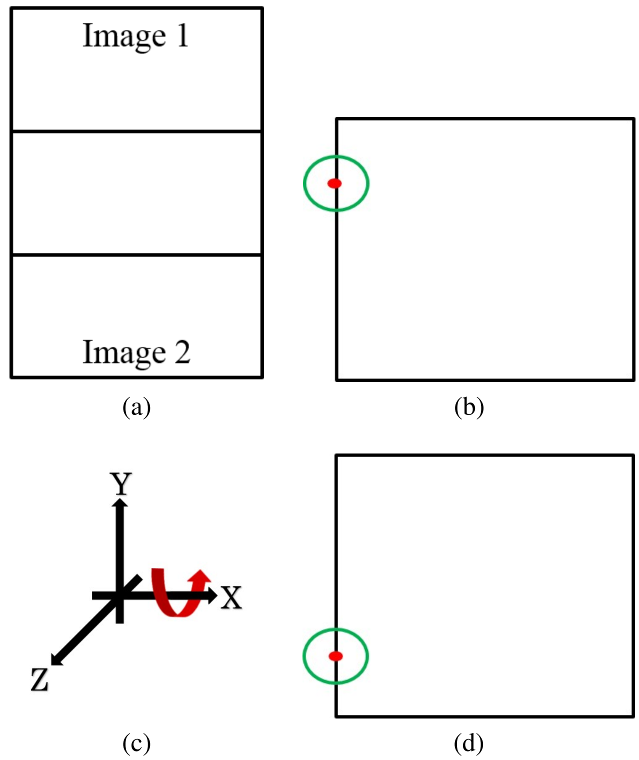


Figure 5.4: (a) Vertically mosaiced image, (b) Cross power spectrum for vertically mosaiced image, (c) Rotation of 180° with respect to X axis, (d) 2D spectrum after rotation.

observed from Fig. 5.5(d) that the location of peak is same as earlier in the X-Y plane except first row and first column in 2D spectrum after rotating spectrum. Thus, both the X coordinate and Y coordinate of the position of peak is changed according to time reversal property in the case of horizontally mosaiced image when the sequence of inputs is changed.

5.3.4 Comparison of Theoretical, Practical and Actual Results

If we consider the case in which input images are stitched horizontally as shown in Fig. 5.6(a), 5.6(b) and 5.6(c). The size of input images are 290×414 and 290×475 respectively. Therefore, the size of spectrum will be $H \times W$ i.e. 290×475 for given inputs. Fig. 5.6(d) shows the spectrum of inputs for given sequence. The distinct peak is at (x_1, y_1) i.e. $(326, 1)$, which is displacement

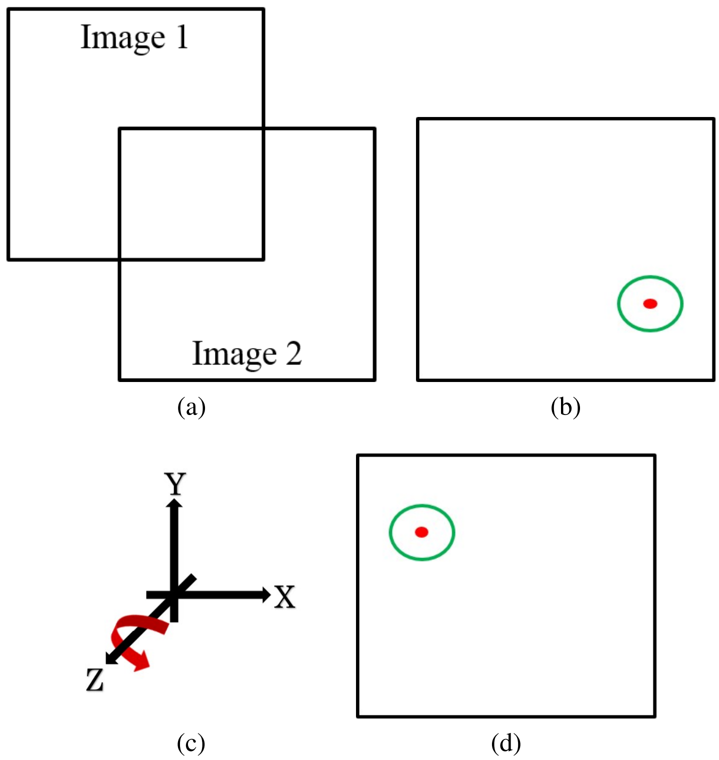


Figure 5.5: (a) Diagonally mosaiced image, (b) Cross power spectrum for diagonally mosaiced image, (c) Rotation of 180° with respect to Z axis, (d) 2D spectrum after rotation.

between two images according to phase correlation method.

If the sequence of the inputs is changed and inputs are applied to method, we will get the position of peak at the $(151,1)$ as shown in the Fig. 5.6(e).

Now theoretically, if the sequence of inputs is changed then the peak should be at $(W+1-x_0, y_0)$ according to Eq. (5.7). By calculation, we will get position at $(150,1)$.

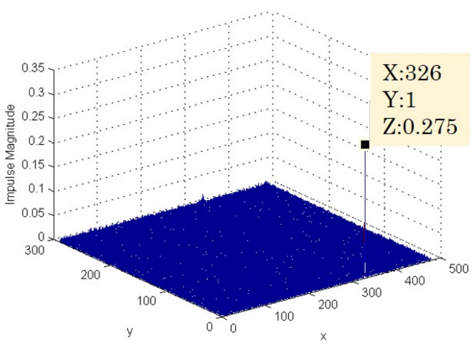
The Table 5.1 shows the comparison of the position of peak in the spectrum obtained by theoretical analysis and practical analysis with actual position. The theoretical result is obtained by using Eq. (5.7), (5.8) and (5.9) derived uisng time reversal property. The practical result is obtained by rotating spectrum.

It can be observed that the position of peaks obtained by practical and theoretical results are differ by only single pixel position horizontally i.e. almost

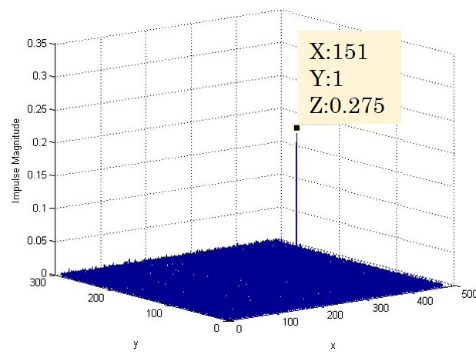
(a)

(b)

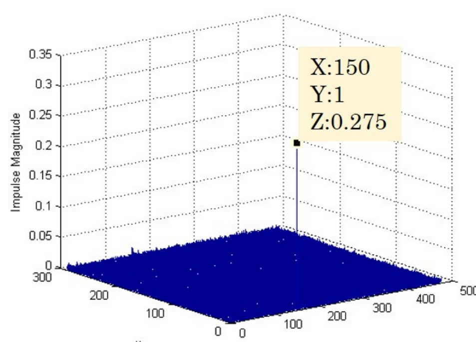
(c)



(d)



(e)



(f)

Figure 5.6: (a) and (b) Input images, (c) Horizontally mosaiced image, (d) Cross power spectrum for given sequence of inputs, (e) Spectrum after rotation of 180° with respect to Y axis, (f) Spectrum after changing the sequence of inputs.

same.

Table 5.1: Comparison of the position of peak in the spectrum for horizontally mosaiced image.

Theoretical	**Practical**	**Actual**
(150, 1)	(150, 1)	(151, 1)

Now if we consider the case in which input images are stitched vertically as shown in Fig. 5.7(a), 5.7(b) and 5.7(c). The size of input images are 266×473 and 249×473 respectively. Therefore, the size of spectrum will be $H \times W$ i.e. 266×473 for given inputs. Fig. 5.7(d) shows the spectrum of inputs for given sequence. The distinct peak is at (x_0, y_0) i.e. $(1, 174)$, which is displacement between two images according to phase correlation method.

If the sequence of the inputs is changed and inputs are applied to method, we will get the position of peak at the $(1, 94)$ as shown in the Fig. 5.7(e).

Now theoretically, if the sequence of inputs is changed then the peak should be at $(x_0, H+1-y_0)$ according to Eq. (5.8). By calculation, we will get position at $(1, 93)$.

The Table 5.2 shows the comparison of the position of peak in the spectrum obtained by theoretical analysis and practical analysis with actual position for the vertically mosaiced image.

Table 5.2: Comparison of the position of peak in the spectrum for vertically mosaiced image.

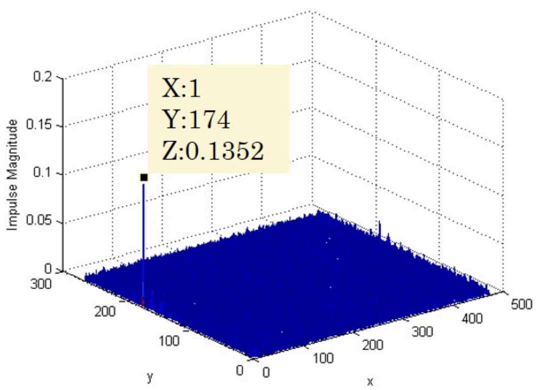
Theoretical	**Practical**	**Actual**
(1, 93)	(1, 93)	(1, 94)

It can be observed that the position of peaks obtained by practical and theoretical results are almost same as actual position. Both positions are differ by only single pixel position vertically.

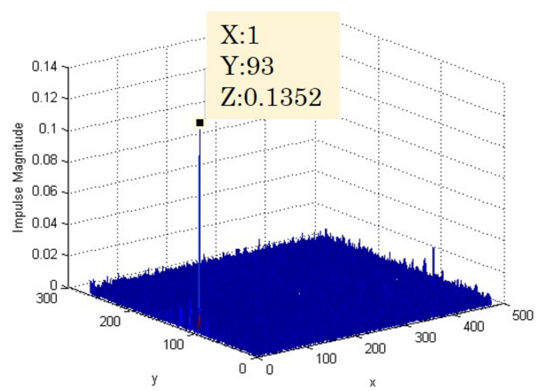
(a)

(b)

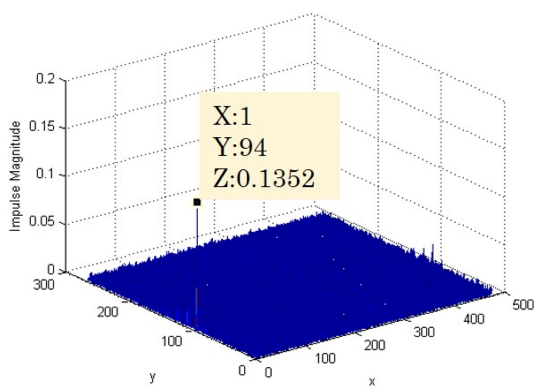
(c)



(d)



(e)



(f)

Figure 5.7: (a) and (b) Input images, (c) Vertically mosaiced image, (d) Cross power spectrum for given sequence of inputs, (e) Spectrum after rotation of 180° with respect to X axis, (f) Spectrum after changing the sequence of inputs.

Now if we consider the case in which input images are stitched diagonally as shown in Fig. 5.8(a), 5.8(b) and 5.8(c). The size of input images are 262×462 and 267×414 respectively. Therefore, the size of spectrum will be $H \times W$ i.e. 267×462 for given inputs. Fig. 5.8(d) shows the spectrum of inputs for given sequence. The distinct peak is at (x_0, y_0) i.e. $(339, 29)$, which is displacement between two images according to phase correlation method.

If the sequence of the inputs is changed and inputs are applied to method, we will get the position of peak at the $(125, 240)$ as shown in the Fig. 5.8(e).

Now theoretically, if the sequence of inputs is changed then the peak should be at $(W + 1 - x_0, H + 1 - y_0)$ according to Eq. (5.9). By calculation, we will get position at $(124, 239)$.

The Table 5.3 shows the comparison of the position of peak in the spectrum obtained by theoretical analysis and practical analysis with actual position for the diagonally mosiced image.

Table 5.3: Comparison of the position of peak in the spectrum for diagonally mosaiced image.

Theoretical	**Practical**	**Actual**
(124, 239)	(124, 239)	(125, 240)

It can be observed that the position of peaks obtained by practical and theoretical results are almost same as actual position. Both positions are differ by only single pixel position diagonally.

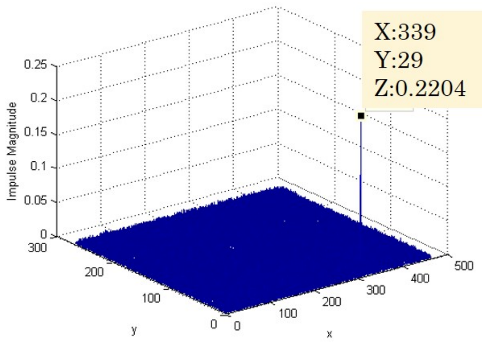
5.4 Proposed Solution

We have discussed in above section that the locations of peak in the cross power spectrum after changing the sequence of inputs obtained by theoretical and practical results are approximately same. Both are differ by single pixel distance in horizontal, vertical or diagonal direction in spectrum depending on the

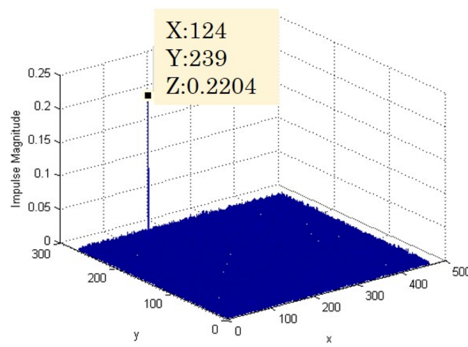
(a)

(b)

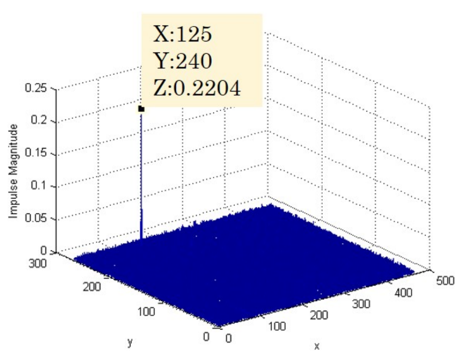
(c)



(d)



(e)



(f)

Figure 5.8: (a) and (b) Input images, (c) Diagonally mosaiced image, (d) Cross power spectrum for given sequence of inputs, (e) Spectrum after rotation of 180° with respect to Z axis, (f) Spectrum after changing the sequence of inputs.

case discussed above. We can define a relation between locations of peak in the spectrum before change of sequence of inputs and the location of peak in spectrum after changing sequence using Eq. (9), (10) and (11). If (x_1, y_1) is the location of peak in the spectrum for given sequence of inputs then the location (x_2, y_2) of peak in the spectrum after changing the sequence is given by,

$$x_2 = \begin{cases} x_1 & x_1 = 1 \\ W - x_1 + 2 & otherwise \end{cases} \tag{5.10}$$

$$x_2 = \begin{cases} x_1 & x_1 = 1 \\ W - x_1 + 2 & otherwise \end{cases} \tag{5.11}$$

where x_1, x_2 indicate the number of column and y_1, y_2 indicate number of row. $H \times W$ is the size of cross power spectrum.

5.5 Proposed Input Sequence Independent Algorithm

In our proposed algorithm we first find the location of peak in spectrum as given input sequence. Then the location of peak in spectrum after changing sequence of inputs is found using above equations. Then, both inputs are mosaiced using these two locations. Using above relation, we do not need to find spectrum using rotate the spectrum to find second mosaiced image. Thus, both result will reduce computation, save the time of processing and also reduce the hardware components for practical implementation.

After finding two mosaiced fingerprints using translation parameter estimated in both original spectrum and spectrum after changing the sequence of inputs, we need to choose the correct output among two outputs. The proposed algorithm again uses the phase correlation method to choose correct mosaiced fingerprint. We find cross phase spectrum of first (left side) fingerprint and the overlapping region for both cases. The height of the peak in spectrum is used to measure similarity between processed images. The case, which has higher peak, has the more similar images i.e. the correct mosaiced fingerprint. Here, we use first input fingerprint with overlapping region to find cross phase spectrum because we superimpose the second input fingerprint on the first input fingerprint at the overlapping region in the mosaicing process. Thus, the overlapping region in mosaiced fingerprint is actually part of second input fingerprint. Therefore, the case, in which the overlapping region is highly correlated with the first input fingerprint, is the correct mosaiced fingerprint. Fig. 5.9 shows the block diagram of proposed sequence independent algorithm.

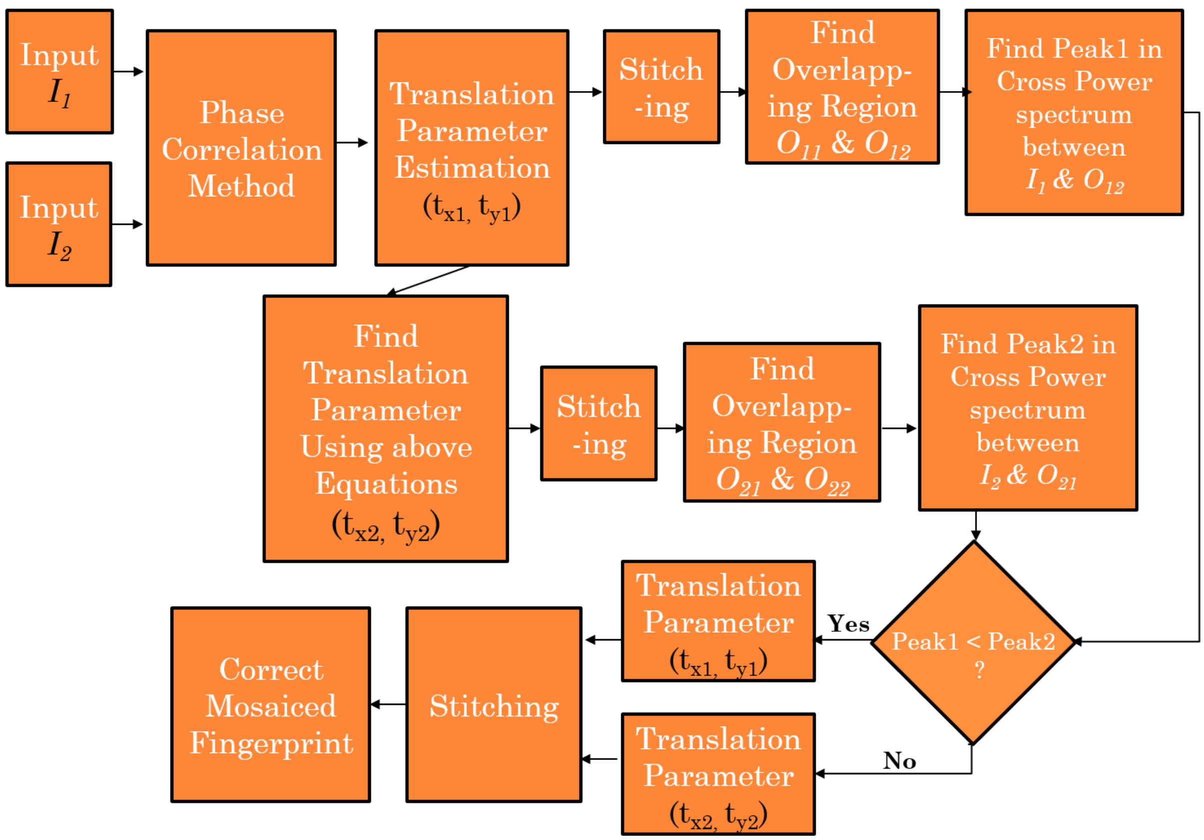


Figure 5.9: Block diagram of proposed sequence independent algorithm

5.6 Results and Discussion

5.6.1 Type 1: Horizontally Mosaiced Fingerprint

First we consider the case of horizontally mosaiced fingerprint. We have taken two input fingerprints as shown in Fig. 5.10(a) and 5.10(b). First, the translation parameter is estimated for given sequence of inputs as shown in Fig. 5.10(c). The overlapping region is found using estimated parameter in second input as shown in Fig. 5.10(d). Now, the translational parameter is estimated for inputs of the changed sequence using the Eq. (5.10) and (5.11). Note that we find the translation parameter for changed sequence using two simple equation, without finding spectrum which reduces the computation and improves the speed of the algorithm. As first input becomes second after changing the sequence, the overlapping region is found using estimated parameter in first input as shown Fig. 5.10(f). Now, the cross power spectrum of obtained overlapping region of one input and other image is found. Thus, spectrum of overlapping region of Fig. 5.10(d) and input of Fig. 5.10(a) is shown in 5.10(h). The spectrum of overlapping region of Fig. 5.10(f) and input of Fig. 5.10(b) is shown in 5.10(i). It can observed that the magnitude of peak in 5.10(i) is greater than that of 5.10(h). The greater peak indicates that the sequence of inputs in that case is correct which leads to obtained correct mosaiced fingerprint.

Similarly, we can get results for other two cases of vertically mosaiced fingerprint and diagonally mosaiced fingerprint. Fig. 5.11 shows the results for the vertically mosaiced fingerprint and 5.12 shows the results for the diagonally mosaiced fingerprint.

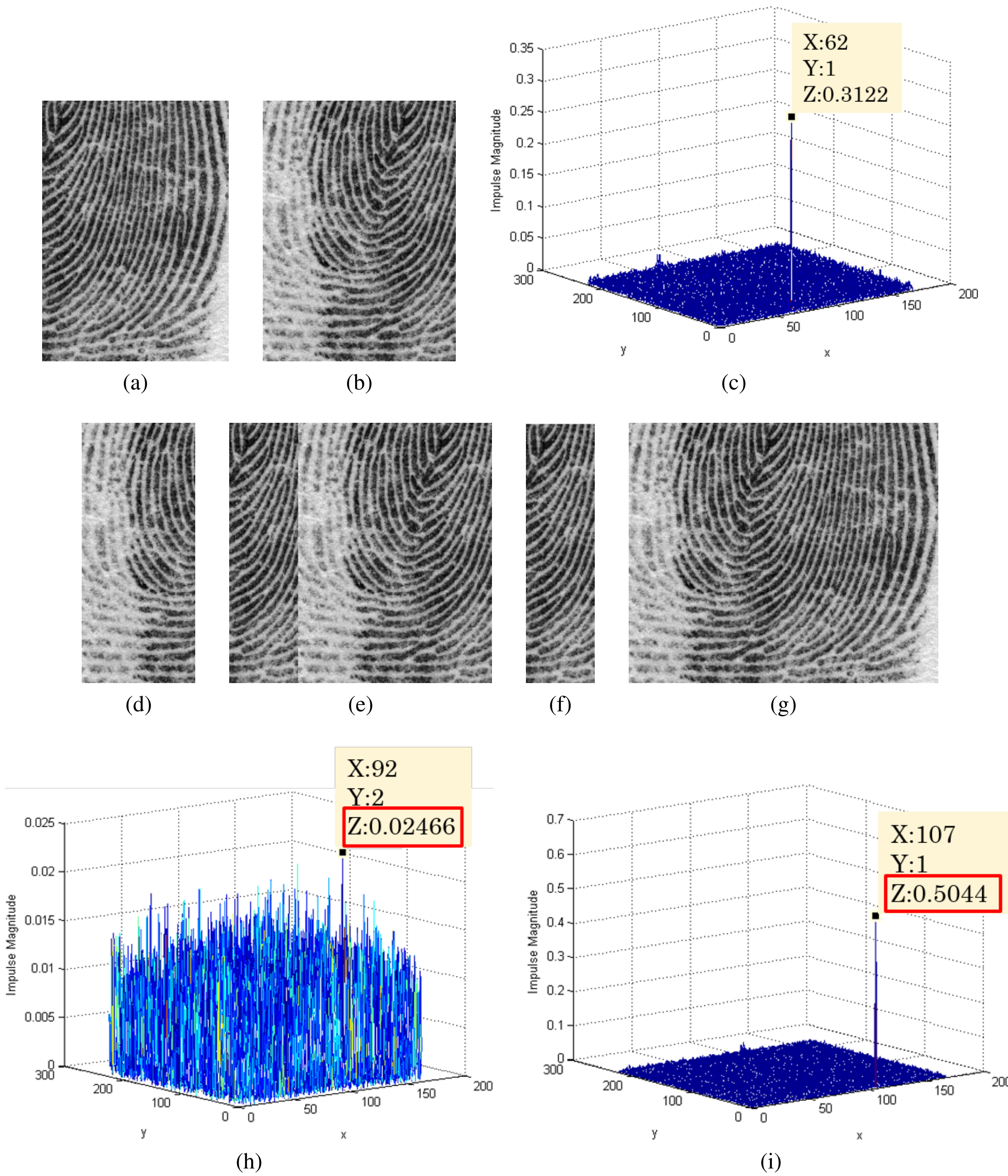


Figure 5.10: (a) and (b) Input fingerprints, (c) Cross power spectrum of inputs, (d)Estimated overlapping region of second input, (e) Mosaiced fingerprint according to spectrum of (c), (f) Overlapping region of first input using Eq. (5.10) and (5.11), (g) Mosaiced fingerprint according to estimated translation parameter using Eq. (5.10) and (5.11), (h) Spectrum of first input and overlapping region of (d), and (i) Spectrum of second input and overlapping region of (f).

5.6.2 Type 2: Vertically Mosaiced Fingerprint

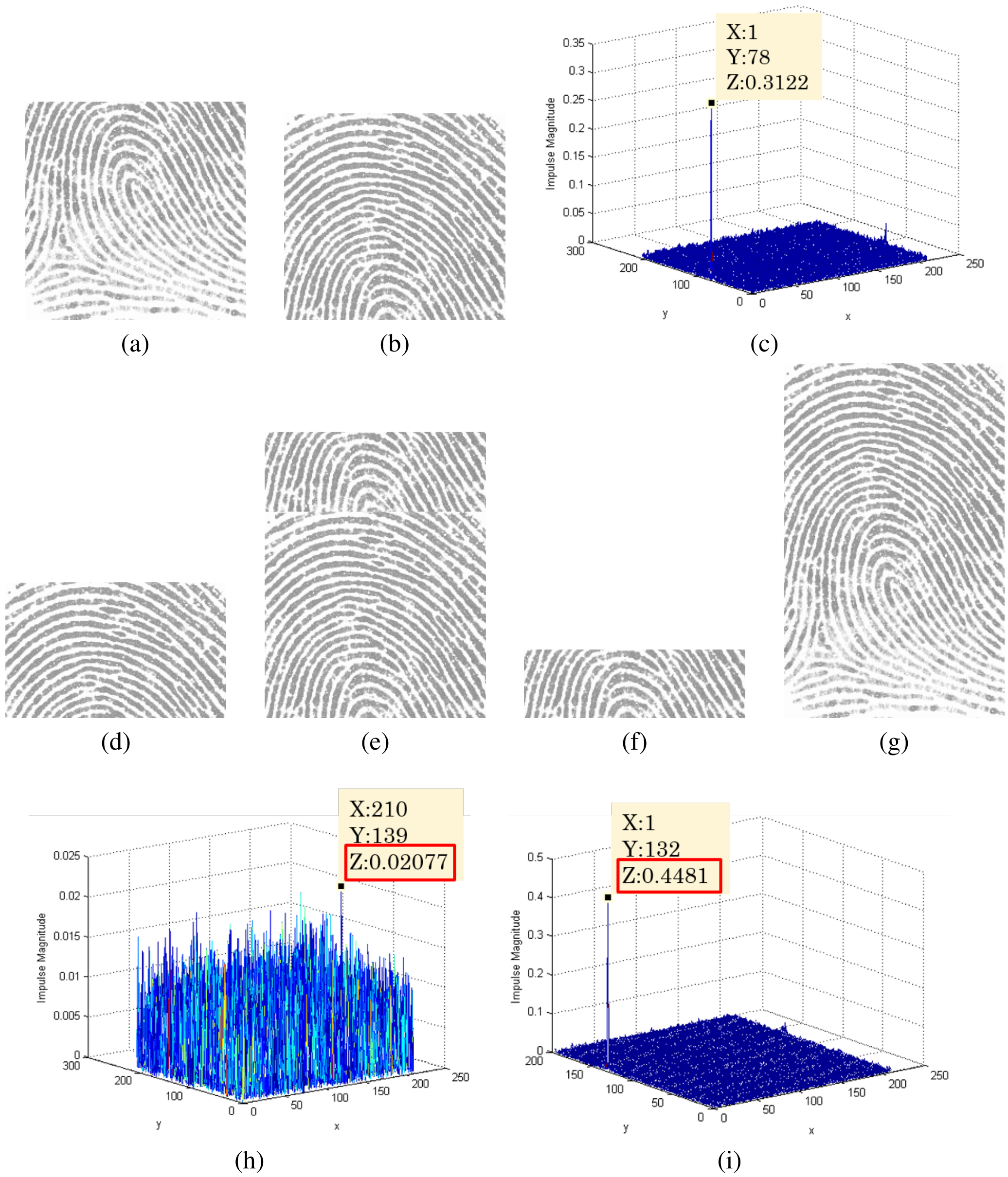


Figure 5.11: (a) and (b) Input fingerprints, (c) Cross power spectrum of inputs, (d)Estimated overlapping region of second input, (e) Mosaiced fingerprint according to spectrum of (c), (f) Overlapping region of first input using Eq. (5.10) and (5.11), (g) Mosaiced fingerprint according to estimated translation parameter using Eq. (5.10) and (5.11), (h) Spectrum of first input and overlapping region of (d), and (i) Spectrum of second input and overlapping region of (f).

5.6.3 Type 3: Diagonally Mosaiced Fingerprint

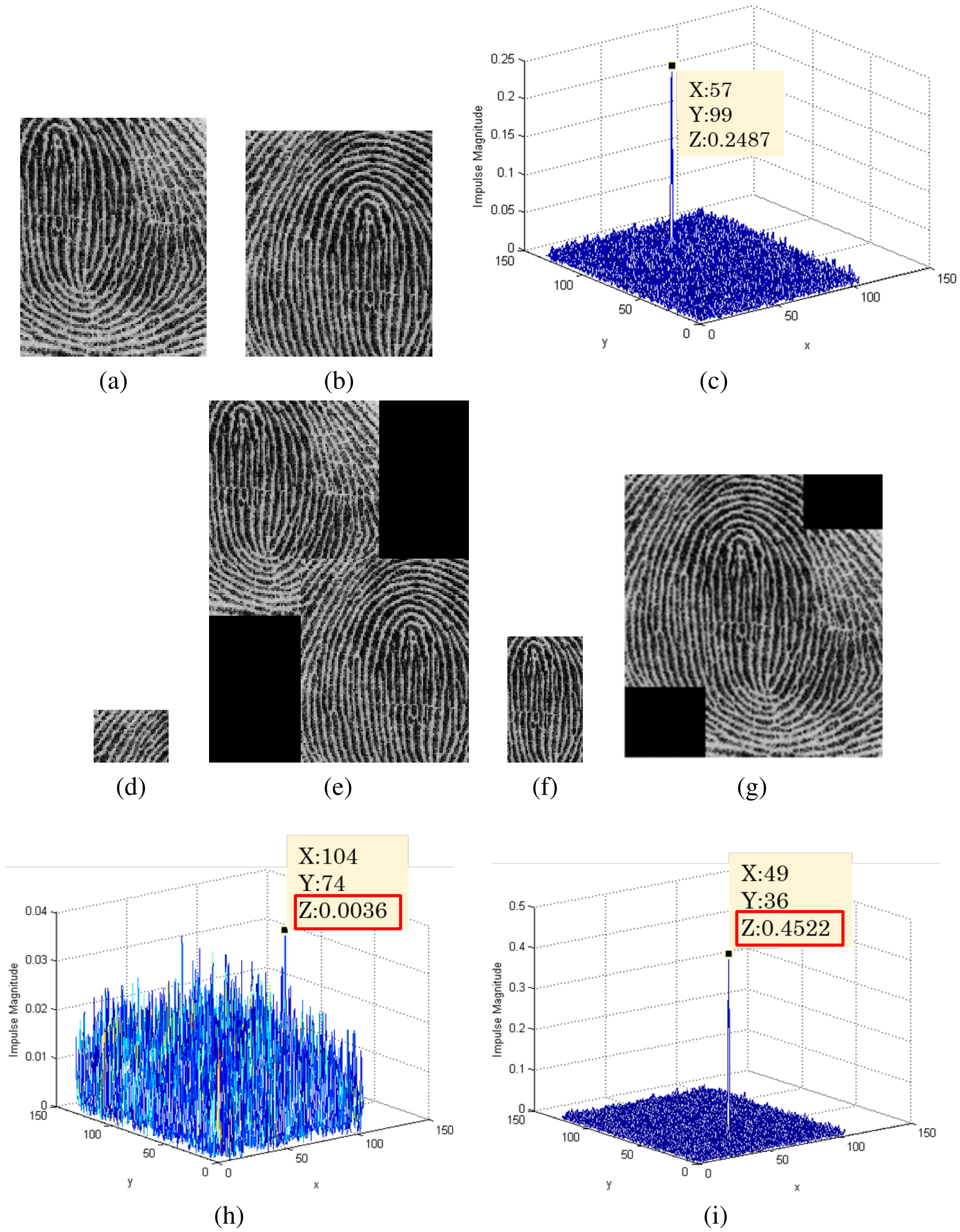


Figure 5.12: (a) and (b) Input fingerprints, (c) Cross power spectrum of inputs, (d)Estimated overlapping region of second input, (e) Mosaiced fingerprint according to spectrum of (c), (f) Overlapping region of first input using Eq. (5.10) and (5.11), (g) Mosaiced fingerprint according to estimated translation parameter using Eq. (5.10) and (5.11), (h) Spectrum of first input and overlapping region of (d), and (i) Spectrum of second input and overlapping region of (f).

5.7 Summary

The proposed input sequence independent algorithm generates correct output mosaiced fingerprint for any sequence of inputs. As the translation parameter for the changed sequence is determined using simple two equation, the algorithm needs less computation. Thus, the proposed algorithm is fast and requires less memory for hardware implementation.

Chapter 6

Proposed Algorithm to check Presence of Overlapping Region

Overview

Proposed Algorithm

Results and Discussion

Summary

Chapter 6

Proposed Algorithm to Check Presence of Overlapping Region

6.1 Overview

The principal of the phase correlation method is to estimate translation parameter at the location of distinct peak in the cross power spectrum. If two images do not have overlapping region still their cross power spectrum has many peaks. In such case, the algorithm still considers a peak with maximum magnitude compare to other peaks as distinct peak and estimates the displacement at the location of that peak. As the images do not have common region, the method generates incorrect mosaiced image using estimated wrong translation parameter.

6.2 Proposed Algorithm

Our proposed algorithm can check whether the input fingerprints have common overlapping region or not. If the inputs have overlapping region then the algorithm generates mosaiced fingerprint image otherwise displays the message "No overlapping region in input fingerprints". Fig. 6.2 shows the block diagram of proposed correctness check algorithm.

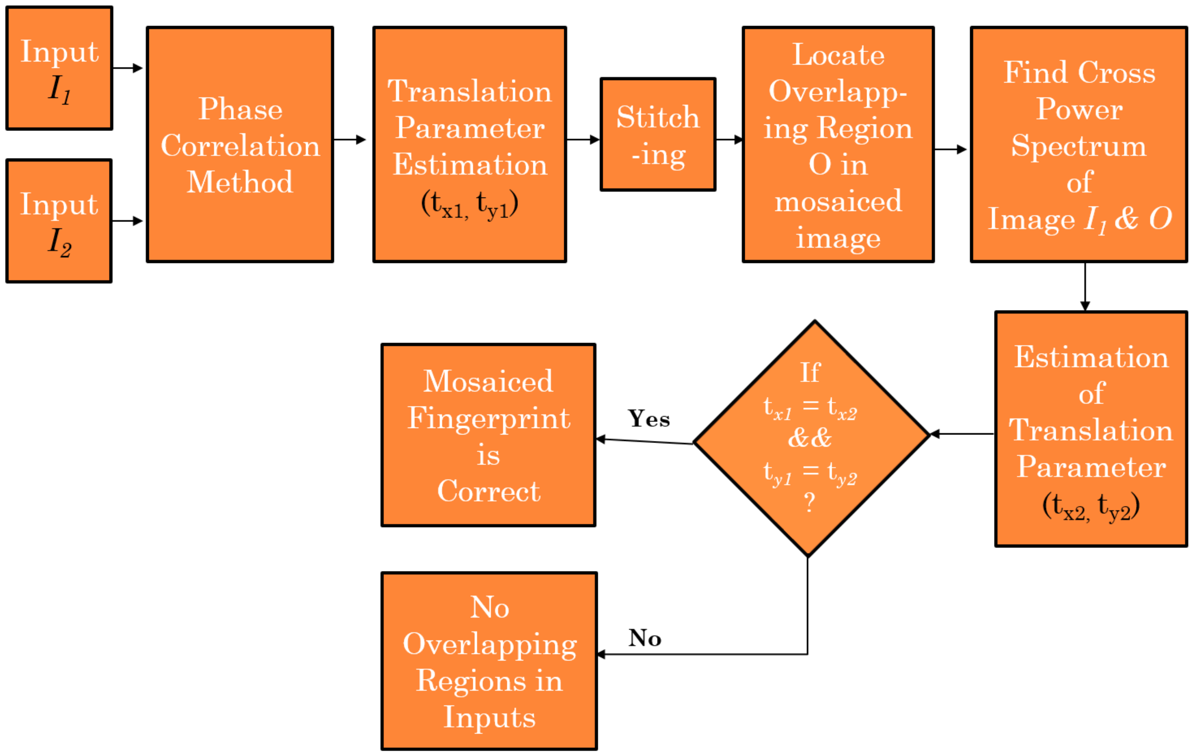


Figure 6.1: Block diagram of proposed algorithm

6.3 Results and Discussion

6.3.1 Fingerprints having Overlapping Region

We have taken two input fingerprints as shown in Fig. 6.2(a) and 6.2(b) to check whether inputs have common overlapping region. Fig. 6.2(c) shows the cross power spectrum of inputs. Now, we find the overlapping region in the both inputs using estimated translational parameter. Then, the spectrum between overlapping region of second input (Fig. 6.2(g)) and the first input is determined. The spectrum is shown in Fig. 6.2(h). If can be seen from Fig. 6.2(c) and 6.2(g) that the peak in both the spectrums have exact same location. Thus, the inputs have common overlapping region. The Fig. 6.2(h) shows the mosaiced fingerprint obtained by stitching inputs on overlapping region.

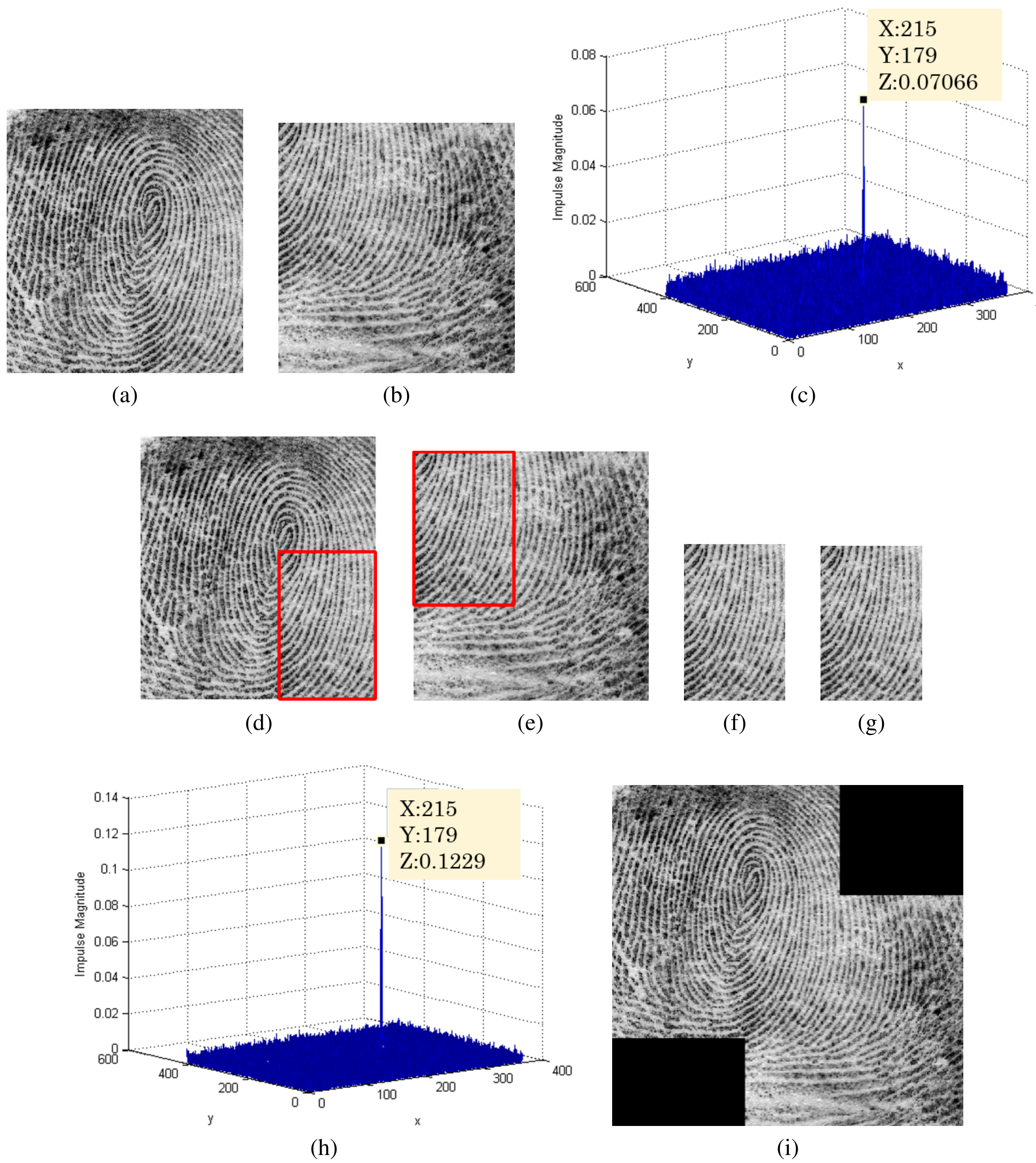


Figure 6.2: (a) and (b) Input fingerprints, (c) Cross power spectrum of inputs, (d) and (e) Estimated overlapping region in the inputs respectively, (f) and (g) Overlapping regions respectively, (h) Cross power spectrum of first input and overlapping region of second fingerprint, (i) Mosaiced fingerprint using estimated parameter of spectrum in (c).

6.3.2 Fingerprints having No Overlapping Region

Here, we have taken two input fingerprints as shown in 6.3(a) and 6.3(b) and applied to proposed algorithm as described in previous subsection 6.3.1. It is seen from Fig. 6.3(c) and 6.3(h) that the spectrums have not peak at same location. These different locations indicates that the input fingerprints do not have common overlapping region. However, if the inputs are stitched then it generates incorrect mosaiced fingerprint as shown in 6.3(i).

6.4 Summary

The proposed algorithm determines the overlapping region in the second input using the phase correlation method. The algorithm again finds the location of peak in spectrum of overlapping region and first input. The algorithm compares the location of peak in the spectrum of inputs and the spectrum of overlapping region and first input to check the presence of the common overlapping region.

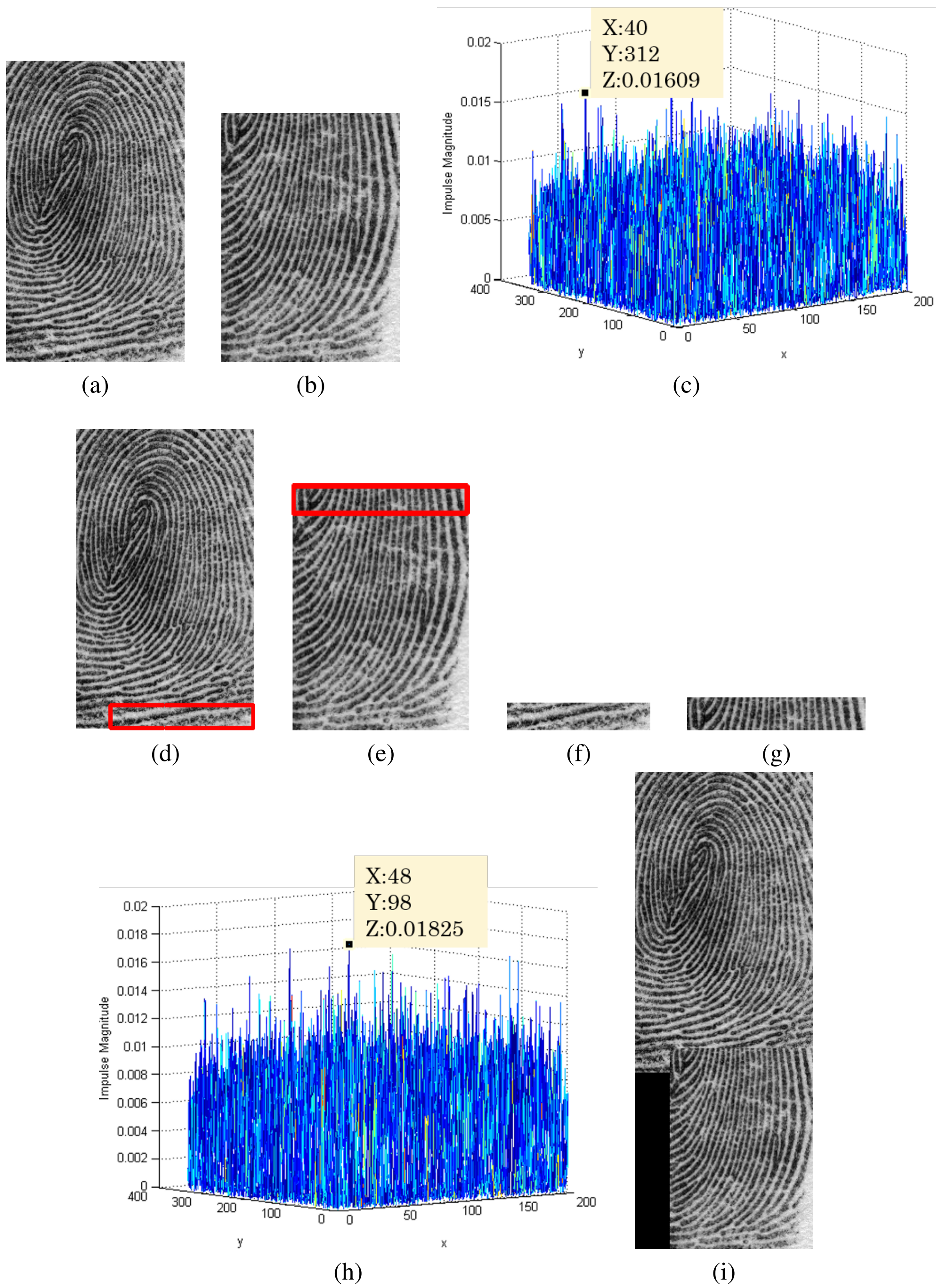


Figure 6.3: (a) and (b) Input fingerprints, (c) Cross power spectrum of inputs, (d) and (e) Estimated overlapping region in the inputs respectively, (f) and (g) Overlapping regions respectively, (h) Cross power spectrum of first input and overlapping region of second fingerprint, (i) Mosaiced fingerprint using estimated parameter of spectrum in (c).

Chapter 7

Conclusion and Future Scope

Conclusion

Future Scope

Chapter 7

Conclusion and Future Scope

7.1 Conclusion

The proposed algorithm gives correct mosaiced fingerprint even though the overlapping region is not in the leftmost top corner of fingerprint. The proposed algorithm is sequence independent of inputs. It generates same correct mosaiced fingerprint for both sequence of inputs. The proposed algorithm is able to check the correctness of the output mosaiced fingerprint. The proposed algorithm solves the all the limitation of the conventional phase correlation method and improves the accuracy, robustness and efficiency of the conventional method.

7.2 Future Scope

The algorithm can be extended to estimate scaling parameter involved in fingerprints because of elastic deformation. All the proposed algorithms can be combined and a robust and efficient automatic fingerprint mosaicing system can be developed. A fingerprint matching algorithm can also be added to system to make an automatic partial fingerprint matching system which detects the minutiae points in the mosaiced fingerprints and match with stored database.

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2. Satish H. Bhati and Umesh C. Pati, “Phase Correlation based Algorithm using Fast Fourier Transform for Fingerprint Mosaicing,” *3rd International Conference on Advanced Computing, Networking, and Informatics, Springer*, Bhubaneswar, June 2015. (accepted)